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HIGH-RATE FILTRATION STUDY AT GAFFNEY, SOUTH CAROLINA, WATER PLANT

Gordon G. Robeck

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

May 1963

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PROJECT REPORT

Title-HIGH-RATE FILTRATION STUDY AT

GAFFNEY, SOUTH CAROLINA, WATER PLANT

1. Gaffney, S.C. - water plant
2. Filters and filtration
3. Water - purification
filtration
see
filters and filtration
main entry

by

Gordon G. Robeck

Engineering Section
Basic and Applied Sciences Branch
Division of Water Supply and Pollution Control

May, 1963

In Cooperation with South Carolina State Board of Health and the Board of Public Works, Gaffney, S. C.

U. S. Department of Health, Education, and Welfare
Public Health Service
Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

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PARTICIPATING AGENCIES AND PERSONNEL

Various agencies and people listed below were involved in the planning, instrumenting, operating, and report writing for this project, but most credit for its completion belongs to the plant operators.

Gaffney Board of Public Works

B. Claude Vassey, Chairman

Zeb V. Whelchel, Treasurer

M. B. Salmon, Secretary

George C. Wright, Manager (1959 to April 1960)

R. C. Carroll, Manager (starting in summer of 1960)

Gaffney Water Plant

Neil Petty, Superintendent

J. Victor Bolin, Operator

Lamar Hammett, Operator

Neal Martin, Operator

South Carolina State Board of Health, Columbia, S. C.,
Water and Sewage Section, Division of Sanitary Engineering

Thomas P. Anderson

John Jenkins

U.S. Department of Health, Education, and Welfare
Public Health Service
Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio
Engineering Section of Division of Water Supply and Pollution Control

R. L. Woodward, Chief of Engineering Section

Gordon G. Robeck, Project Engineer

Eugene Donovan, Engineer

Glenn Gruber, Mechanic

Robert Zanone, Engineering Aide

HIGH-RATE FILTRATION STUDY
AT GAFFNEY, SOUTH CAROLINA WATER PLANT

Gradual changes and improvements in the coagulation and chlorination processes at many water treatment plants have altered the role of the filtration process to such a degree that a review of the function and design of the filter is called for. As a part of this review the Sanitary Engineering Center has cooperated with various State Health Departments and water plants to collect data on the influence of higher rates of filtration on the quality of finished water. This report covers a project carried out in a 3-mgd water plant at Gaffney, South Carolina, from 1959 to 1961. The results emphasize the fact that, when a coarse anthracite filter media is used adequate coagulation is essential to obtain clear water regardless of filter rates. When the coagulation process functioned properly, well-clarified water was obtained at a filtration rate between 1 to 6 gpm per square foot.

OBJECTIVE

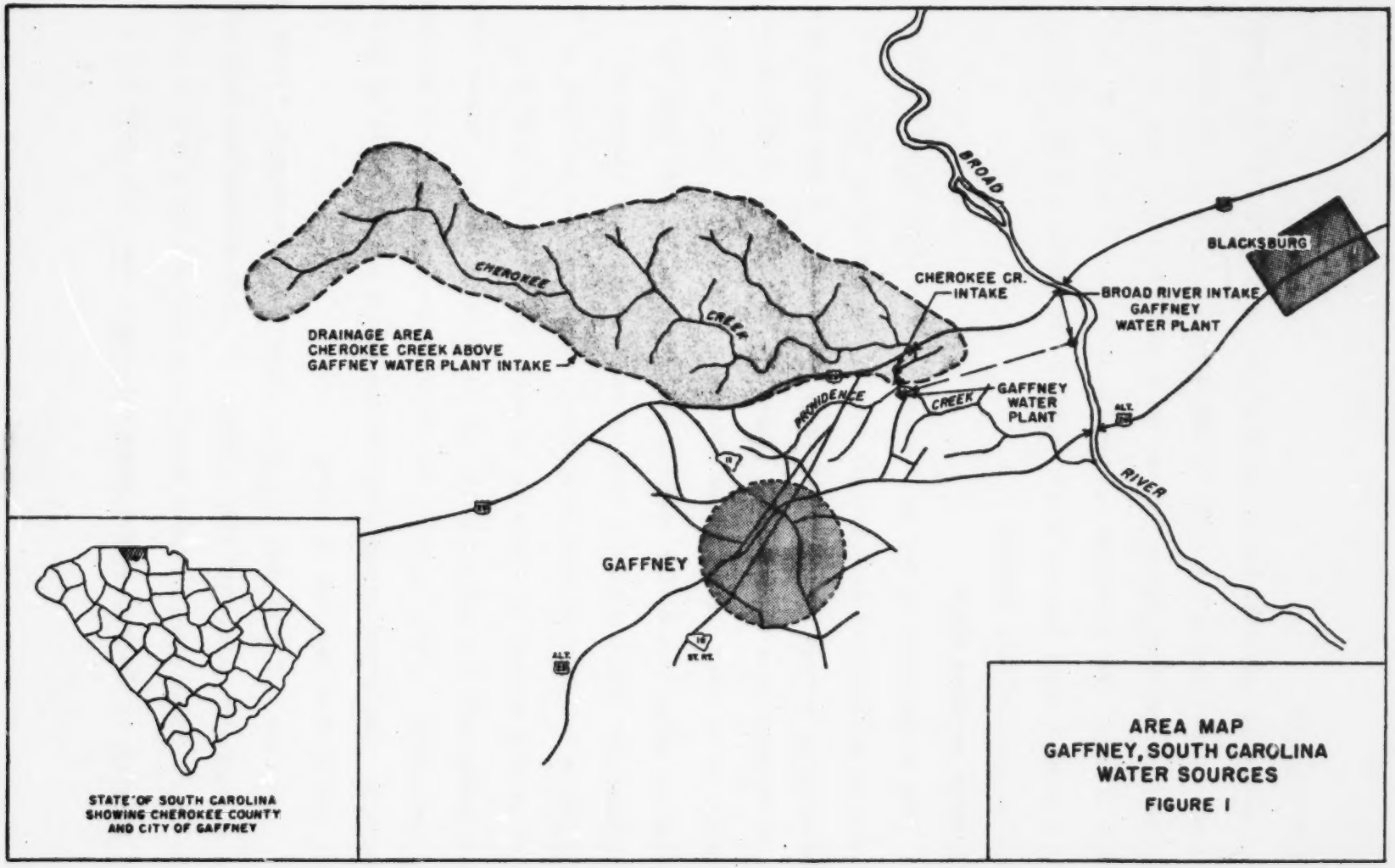
This study originated with a request from the Board of Public Works of the city of Gaffney to the South Carolina State Board of Health for permission to increase water plant throughput beyond the rated capacity of the plant without changing the existing structures. Since this would involve shorter flocculation, shorter retention time in the sedimentation basin, and higher filtration rates, and since the state officials would not normally permit such changes without good cause they asked the U. S. Public Health Service if there were any new research findings on the matter. Although a

number of reports on the use of filtration rates higher than the standard 2-gallon per minute per square foot rate have appeared, these have involved relatively large plants; there is a dearth of information about small water plants with a single operator per shift. Inasmuch as water filter design was being studied at the Sanitary Engineering Center, a cooperative project was arranged with state and local authorities to investigate the performance of the Gaffney plant at various filter rates. The project consisted of monitoring plant effluents carefully while adjusting flow through the filters from 1 to 6 gpm per square foot.

Consulting engineers in the Piedmont area of South Carolina were also interested in the objectives, techniques, and progress of the study, and attended joint meetings to better implement the results in old and new plants.

WATER SOURCES AND QUALITY

Cherokee Creek and the Broad River both serve as sources of water for Gaffney. The creek has a drainage area of approximately 18 square miles to the north of the city and mainly west of the treatment plant (Figure 1). The flow is variable, but was about 5 cfs in the fall of 1959. The creek is free from sewage pollution; the land is almost entirely devoted to agriculture. A small dam across the creek near the water treatment plant keeps the pump intake covered, but provides little storage. It is necessary to supplement the creek supply with water from the Board River, which is 2 to 3 miles east of the plant and has a flow of about 725 cfs in the fall. This river is generally of poorer quality than the creek, but responds less quickly than the creek to storms, and so the operator can often avoid the sudden rises in turbidity that occur in the creek after local storms by using


BROAD
BLACKSBURG
CHEROKEE
CREEK
CHEROKEE CR.
INTAKE
BROAD RIVER INTAKE
GAFFNEY
WATER PLANT
DRAINAGE AREA
CHEROKEE CREEK ABOVE
GAFFNEY WATER PLANT INTAKE
PROVIDENCE
CREEK
GAFFNEY
WATER
PLANT
ALT.
RIVER
GAFFNEY
STATE OF SOUTH CAROLINA
SHOWING CHEROKEE COUNTY
AND CITY OF GAFFNEY
AREA MAP
GAFFNEY, SOUTH CAROLINA
WATER SOURCES
FIGURE 1

the river supply.

Generally speaking, the coliform counts per 100 milliliters during the summer months were below 2,000 in the creek and 10,000 in the river. In winter, the coliform loading on the plant was frequently below 300 per 100 milliliters. The turbidity was usually less than 25 Jackson units. Table 1 gives a brief summary of the physical, chemical, and bacteriological characteristics of both sources.

DESCRIPTION OF WATER PLANT

The design capacity for this water treatment plant after its latest revision in 1952 is 3 million gallons per day. A 2-million gallon presettling or storage tank, 12 feet deep, removes some of the turbidity before the water goes to the plant. When this tank is out of service for cleaning, creek water can be pumped directly to the plant. Alum is added immediately ahead of a mixing channel, 300 feet long, 13 feet deep, and 32 inches wide, with under- and overbaffling that provides mixing and flocculation for about 30 minutes at design capacity. The baffling can be placed at 12-5/16-inch intervals in the first 100 feet of channel to get rapid mixing, and then are gradually spread apart in the next segment until they are 3 feet 4 inches apart in the third 100-foot length where slow mixing is desired. The actual energy input during mixing was difficult to estimate since many baffles were not in place.

From the mixing channel the water flows to a distribution trough and then through a stilling wall with sixteen 1- by 1-foot ports for each basin. These ports are arranged in three rows in the bottom half of a 12-1/2-foot stilling wall at the head of the three settling tanks. The ports are 5 feet

Table 1. CHARACTERISTICS OF RAW WATER SOURCES

Characteristics	Summer		Winter	
	Cherokee Creek	Broad River	Cherokee Creek	Broad River
Coliforms, per 100 ml	750-80,000	4,500-140,000	22-720[a]	
Fecal coliforms, per 100 ml	300-3,500[a]			
Fecal streptococci, per 100 ml	1,000-5,700[a]			
pH	6.8-7.3	7.0-7.2	6.7-7.3	7.2-7.4
Alkalinity, mg/liter	14-18		13-22	12-14
Hardness, as $CaCO_3$, mg/liter	14-17		8-12	
BOD, mg/liter				0.2-1.2
Turbidity, J.u.	< 25-750	< 25- > 300	10-1,500[a]	
Water temperature, °F	66-77[a]		34-50	

a) Results from raw water entering plant when there was an approximate 40 to 60 percent mixture of creek and river water.

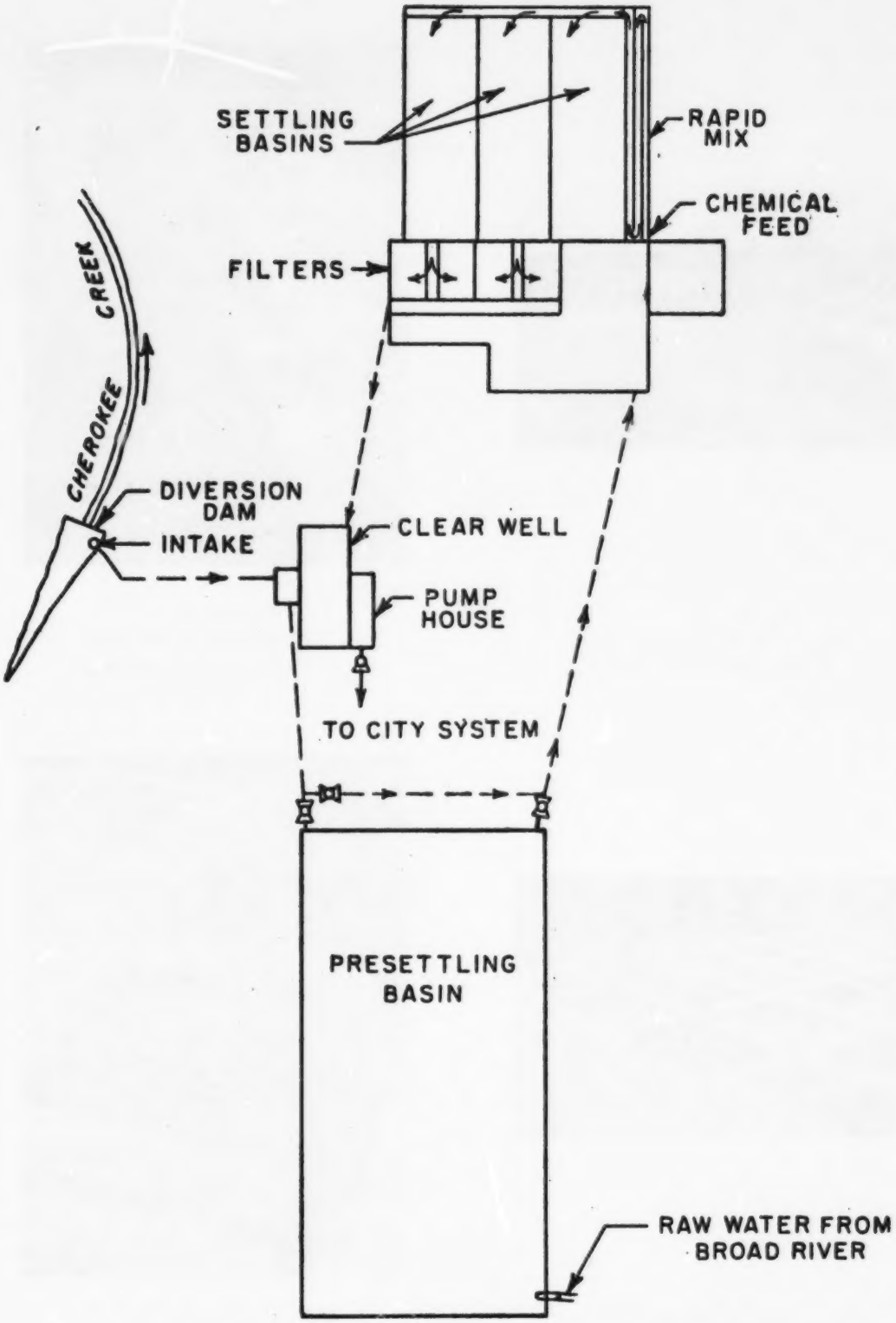
apart horizontally and 2 feet apart vertically. There are also three 8- by 40-inch slots along the bottom of each stilling wall. The tanks are 12 feet deep and the overall surface dimensions are 100 by 100 feet. The theoretical detention time is 6 hours and the overflow rate is 300 gpd per square foot. Outlet weirs across the end convey the water to the filter gullet. Each weir is made from a 12-inch wooden board with 2-inch submerged holes on 12-inch centers, 3 inches from the bottom of the board.

The four filter beds are each 15- by 18-feet, which allows a 2 gpm per square foot rate on the total 1,080 square feet of filter surface at design capacity. In 1952 the filter media consisted of 27 inches of anthracite placed over gravel and a perforated bottom. The sieve analysis of the coal at that time indicated the effective size was about 0.70 millimeter. Core samples from various parts of the beds indicated that, at present, the effective size is still about the same with a uniformity coefficient of 1.75.

There is no surface wash, but the plant has been routinely operated for years so that backwashing was carried out whenever the headloss was only 2 to 3 feet. Thus the filters have remained free of mud balls, even though bed expansion was usually only 3 to 4 inches.

Figure 2 is a layout of the plant and Figures 3, 4, 5, and 5a are pictures showing the plant front view, mixing chambers, settling basins, and filters, respectively.

Valving after each of four filter beds provides an opportunity to preselect a filter for study, and a subsequent rate controller allows for steady flow at a desired rate. Chlorine normally is added before, as well as after, the coagulation-filtration process. During test periods,



PLAN VIEW - GAFFNEY WATER WORKS
GAFFNEY, S.C.
FIGURE 2

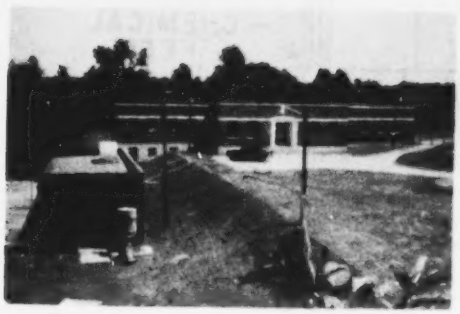


Figure 3
Front View of Treatment
Plant and Pump House

Figure 4
Chemical Mixer and
Flocculation Channels

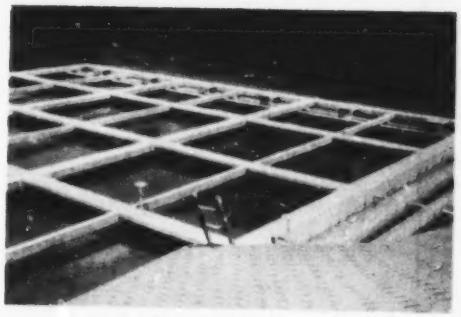


Figure 5

Partial View of
Settling Basins

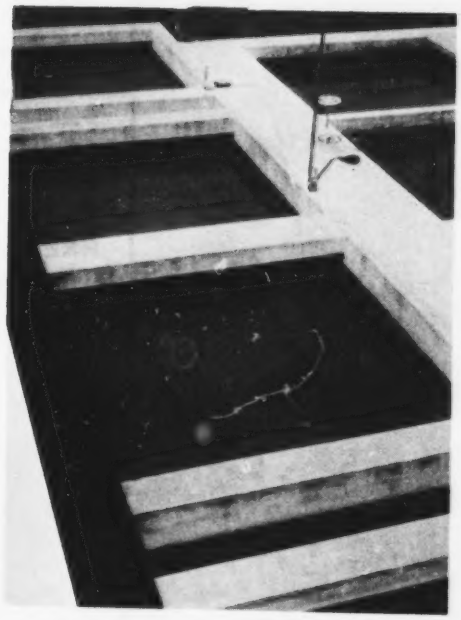


Figure 5a

Top View of
Anthracite Filters

prechlorination was discontinued so a study could be made of coliform passage. Valving and piping around the settling basins were so arranged that the entire flow could be treated in one or two of the three sedimentation basins, which simulated conditions that would exist if plant throughput were increased by two or three times.

From 4 to 15 milligrams per liter of alum were routinely used for flocculation. This dose was introduced at the beginning of the mixing chamber along with some chlorine. Lime was added after filtration to raise the pH from about 6.9 to 7.1 to reduce corrosion in the distribution system. Hexametaphosphate was also added to prevent corrosion.

TEST EQUIPMENT

One purpose of this study was to determine the utility of various water quality-monitoring instruments in a small plant. The original intention was to gauge the turbidity of the water going in and coming out of the filters by three different techniques: (1) A microphotometer with a continuous flow cell and operating on a light-scattering principle was attached to a recorder and initially used to detect the gross turbidity in the various influent and effluent streams. This is a very sensitive, expensive instrument, and somewhat difficult to operate under nonlaboratory circumstances, so a simple Hach turbidimeter was also tried. It soon became evident that this second instrument, based on a 90-degree lightscatter, would suffice for this type of monitoring of gross turbidity. By attaching a galvanometer instead of a recorder to the detector, an operator could get an instantaneous reading on any stream passing through the instrument; (2) a cotton plug method was also tried to compare the turbidity penetration

in parallel filter effluents on an integrated basis over several days; (3) the last technique involved the use of a particle counter to determine the number and size of particles passing the filter. Because of a change in particles while transporting samples, results for the third method were not continued very long on a routine basis. Most of the results are based, therefore, on Hach readings translated into turbidity units. (See Appendix A for brief operating instructions given operators for all three methods.)

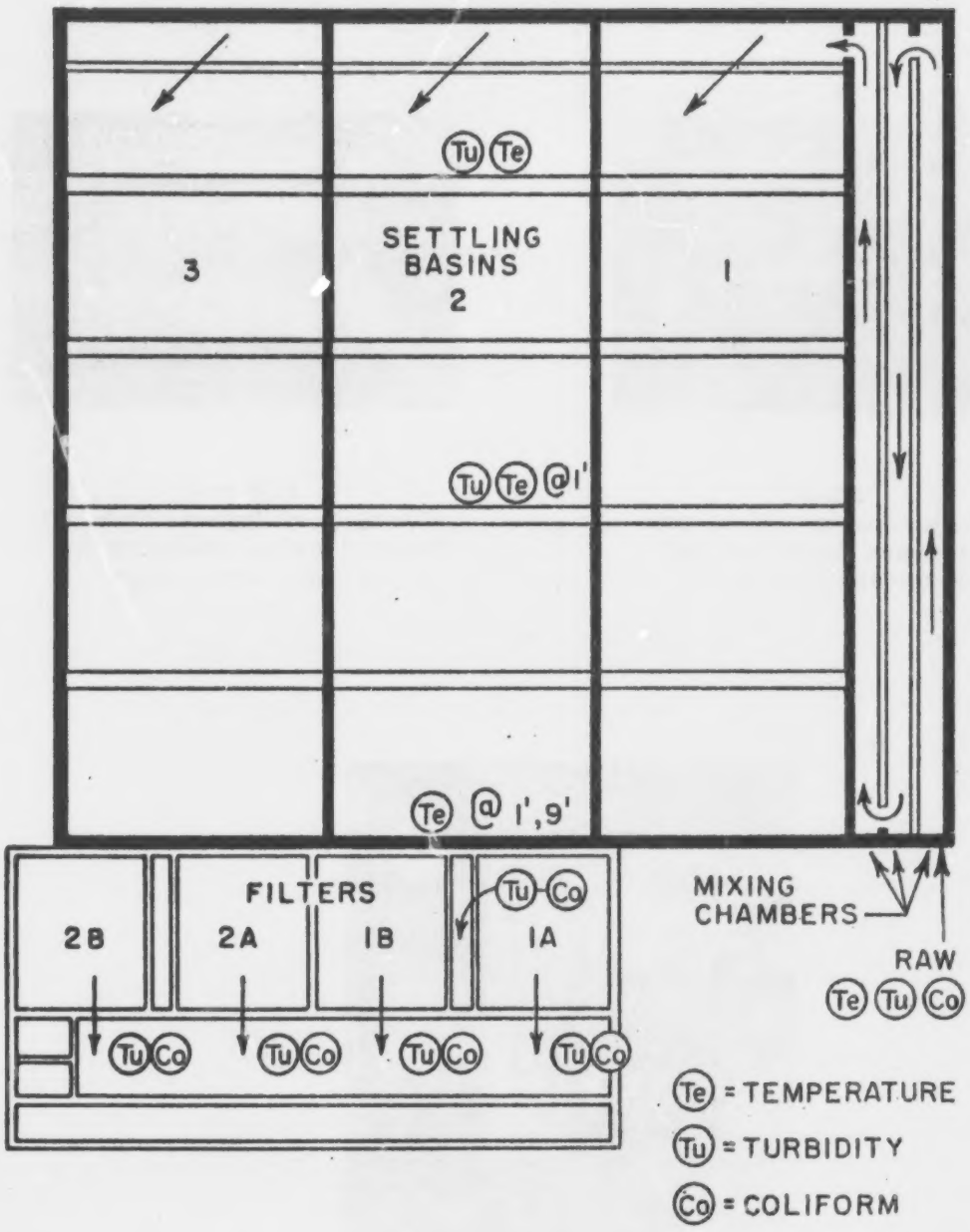
The layout in Figure 6 indicates where equipment was installed and where most routine samples were taken, and Figures 7, 8, and 9 illustrate some of the equipment in operation at the plant. Siphoning action allowed a continuous, small sampling stream to be brought to a manifold ahead of a single detector, and multiple valving permitted any of the many streams to be diverted through the turbidimeter for 20 to 30 minutes.

Coliform organism concentrations in grab samples were assayed by the membrane filter technique. (1)

By extending leads from a sensitive six-outlet telethermometer to various depths and locations in the exposed settling basin, instantaneous temperature readings were obtained as often as changes were likely to be caused by sun or sudden rainfall.

TEST PROCEDURES

Each of the first set of test runs was carried out by first stopping prechlorination and then adjusting the flows through the freshly backwashed filters to preselected rates. Table 2 presents the arrangement of filters, rates, terminal headloss, length of runs, and time of year for each run. Owing to variations in demand there were times when a surplus of water was



SAMPLING LOCATIONS
GAFFNEY, S.C. WATER PLANT

FIGURE 6

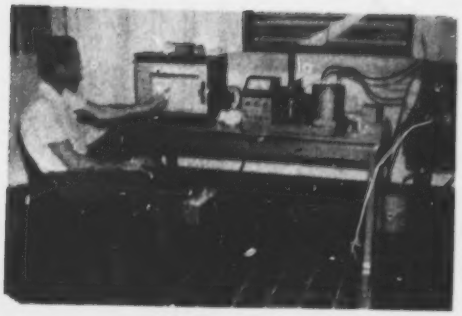


Figure 7
Microphotometer and 11-inch strip chart for detecting and recording turbidity

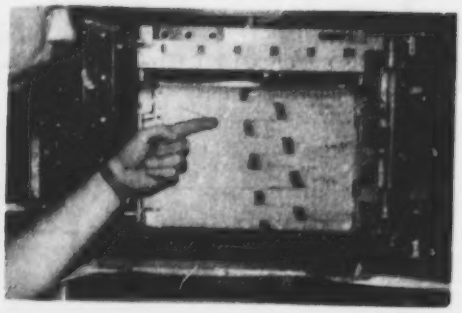


Figure 8
Close-up of Typical Turbidity Results being Recorded on 11-inch strip chart

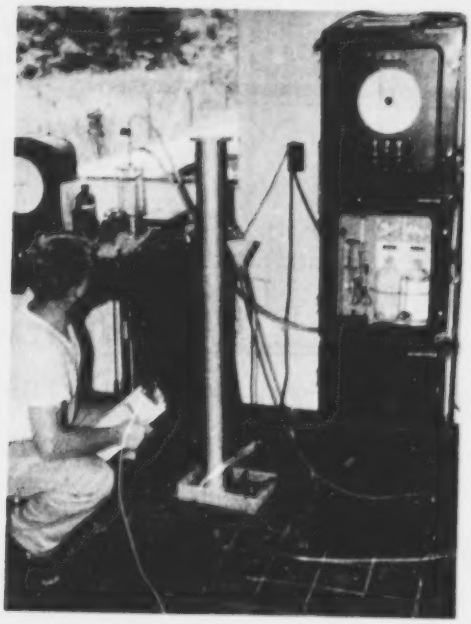


Figure 9

Hach Turbidimeter and Galvanometer setup for Indicating Turbidity. (Chlorine residual Recorder at right)

Table 2. PHYSICAL ARRANGEMENTS FOR TEST FILTER RUNS AT GAFFNEY WATER PLANT

Run No.	Basins in operation	Starting date	Operating time hr	Rate, gpm/sq ft				Terminal headloss, ft.	
				F-1a	F-1b	F-2a	F-2b	F-1	F-2
1	3	8/25/59	91	1		6		1.9	6.6
2	3	8/29/59	82		1		6	0.6	5.9
3	3	9/3/59	144	2		5		2.0	6.2
4	3	9/11/59	133		2		5	2.1	6.0
5	3	9/19/59	117	3		4		2.3	4.3
6	3	9/27/59	89		3		4	3.9	6.0
7	3	10/3/59	150	4		3		6.0	4.2
8	3	10/13/59	104		4		3	3.7	2.6
9	3	10/27/59	127	5		2		6.0	1.6
10	3	11/3/59	137		5		2	6.1	1.8
11	3	11/11/59	93	5.74		1		6.1	0.8
12	3	11/17/59	67.5		5.74	0	1	6.2	1.3
13	2	3/28/60	61.5	5.5		1		6.3	1.2
14	2	4/5/60	115		5		1	6.1	0.8
15	2	4/12/60	123	4.2		2.2		6.2	2.0
16	2	4/19/60	93.5		4.2		2.2	6.1	3.2
17	2	4/26/60	100	3.3		3.3[a]		5.1	6.0[a]
18	2	11/8/60	85	2.2		4.0		2.2	5.6
19	2	11/14/60	88		2.0		4.0	2.4	6.0
20	2	11/28/60	83	1.4		4.5		2.3	6.2
21	2	12/5/60	90		1.4		4.5	1.8	6.0
22	2	12/13/60	65	1.0		5.0		1.5	6.0
23	2	1/3/61	60		1.0		5.0	1.5	4.9
24	2	1/9/61	89.5	4.0		2.0		6.1	3.0
25	2	1/16/61	96		4.0		2.0	4.9	1.4
26	2	1/30/61	81.5	4.5		1.4		6.0	2.0
27	2	2/6/61	68		4.5		1.4	6.2	1.6
28	2	2/13/61	99	5.0		1.0		5.9	1.1
29	2	2/20/61	71		5.0		1.0	6.0	0.9
30	2	4/17/61	163	3.0	3.0	3.0		4.5	3.4

a) Rate on 2a was raised from 3.3 to 4.1 for a few hours before end of run in order to make enough water for uptown; hence, headloss went up to 6.0 feet.

produced under these preset conditions, but the run was usually stopped after 4 or 5 days, so the low-demand periods of the weekend were not involved. This also allowed time for prechlorination to control algae and slimes in the open basins.

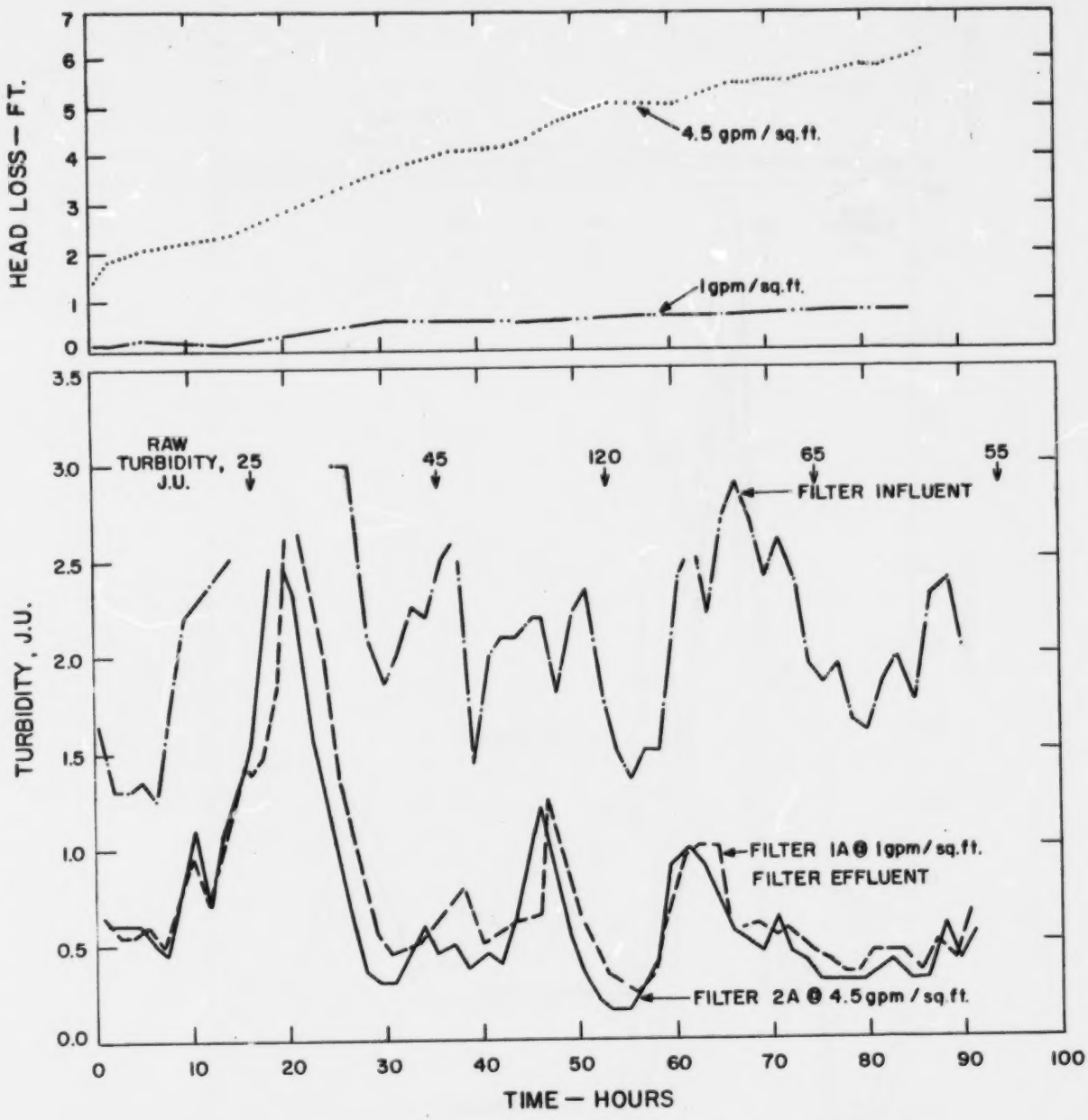
Generally, each of the four filter beds (1A, 1B, 2A, and 2B) was run at each of the rates under investigation (1, 2, 3, 4, 5, and 6 gpm per square foot) at some time during each season. This repetition was to take care of possible differences in the physical condition of any one bed that would not be easily recognized but would influence the results.

After a period of training, the plant operators made all turbidity and coliform determinations and submitted the results weekly to the Sanitary Engineering Center for review and analysis.

RESULTS

Effluent Turbidity

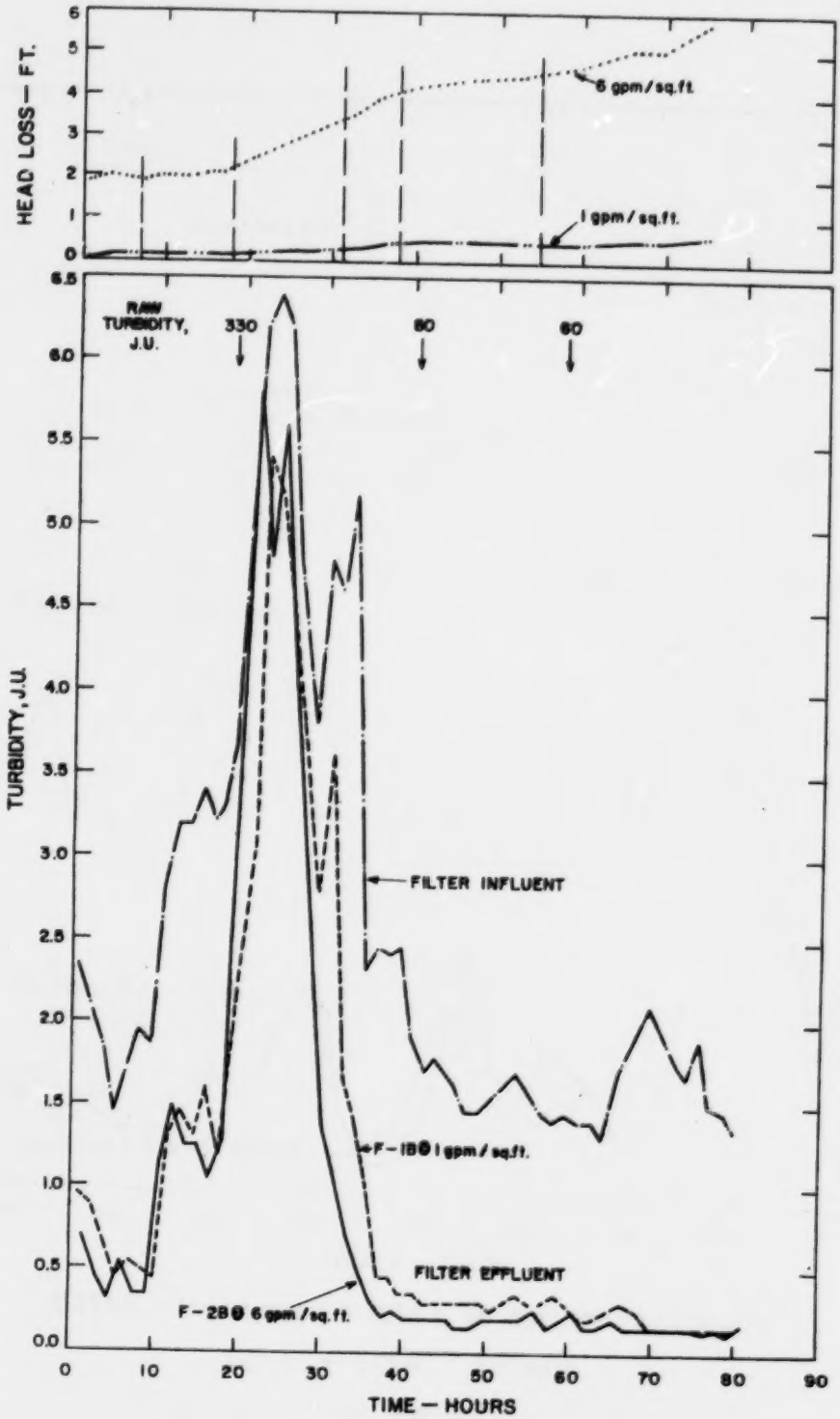
The turbidity results of the test runs (1 to 30) have been presented graphically in Figures 10 through 39 for all four seasons. The first six runs on Figures 10 through 15 illustrate that, during the warm period of late summer, sudden changes in filter effluent quality were caused by an upset settling basin. It was not always clear why the basins were disturbed, but the raw water turbidity of 170 to 330 in run 2 occurred so quickly that inadequate coagulation probably caused the poorly formed floc to penetrate the filter regardless of rate. In both runs 1 and 2 the filter with a 6 gpm per square foot rate did as well as the filter with a 1 gpm per square foot rate. On other occasions, it was apparent that the hot sun caused the water and floc in the basin to rise and flow excessively onto the filters. There



TURBIDITY VALUES AT 1 AND 4.5 gpm/ sq.ft. RATES

RUN # 1, 8/25 — 29/59

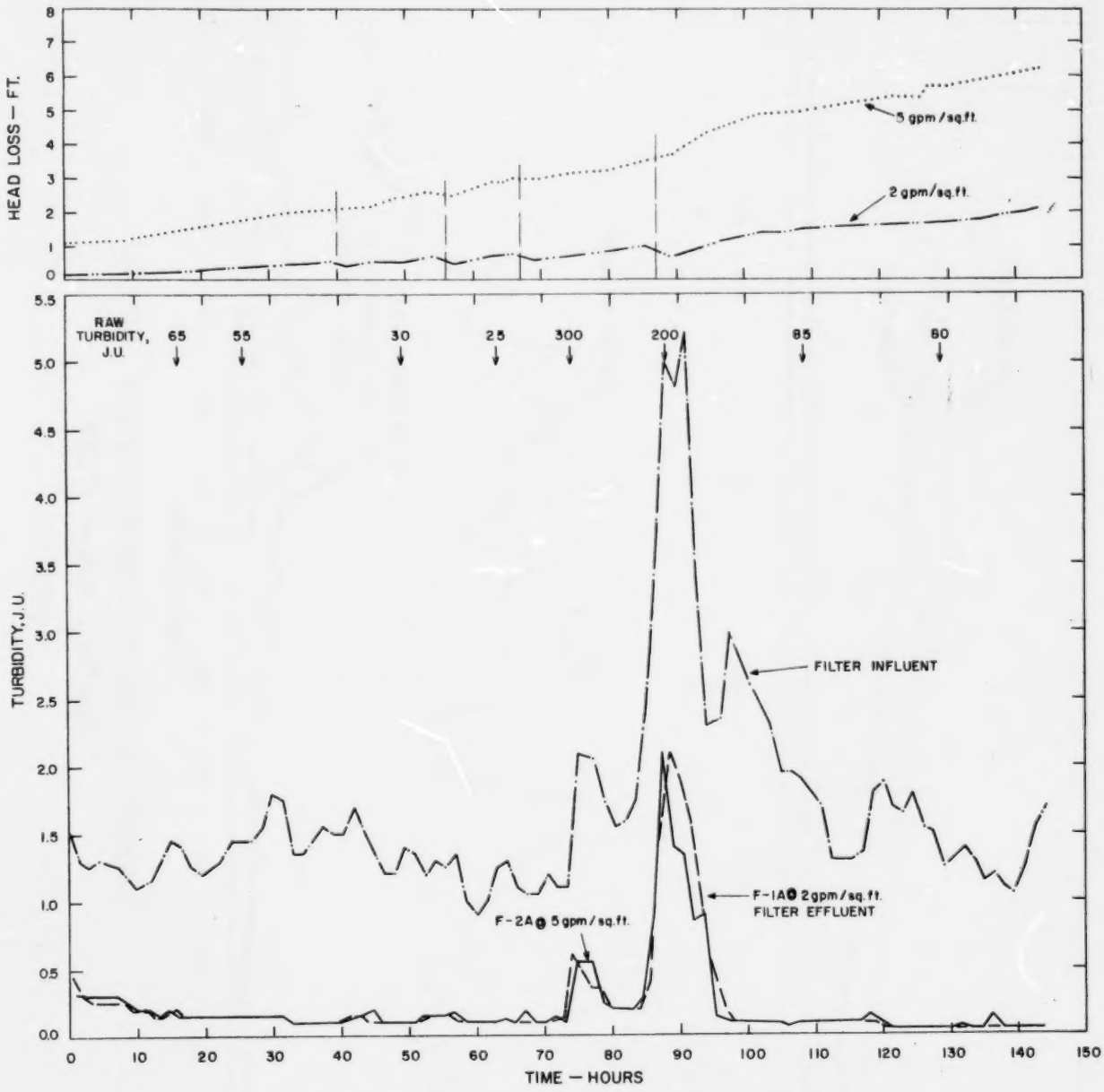
FIGURE 10



TURBIDITY VALUES AT 1 AND 6 gpm/sq.ft. RATES

RUN # 2 8/29— 9/3/59

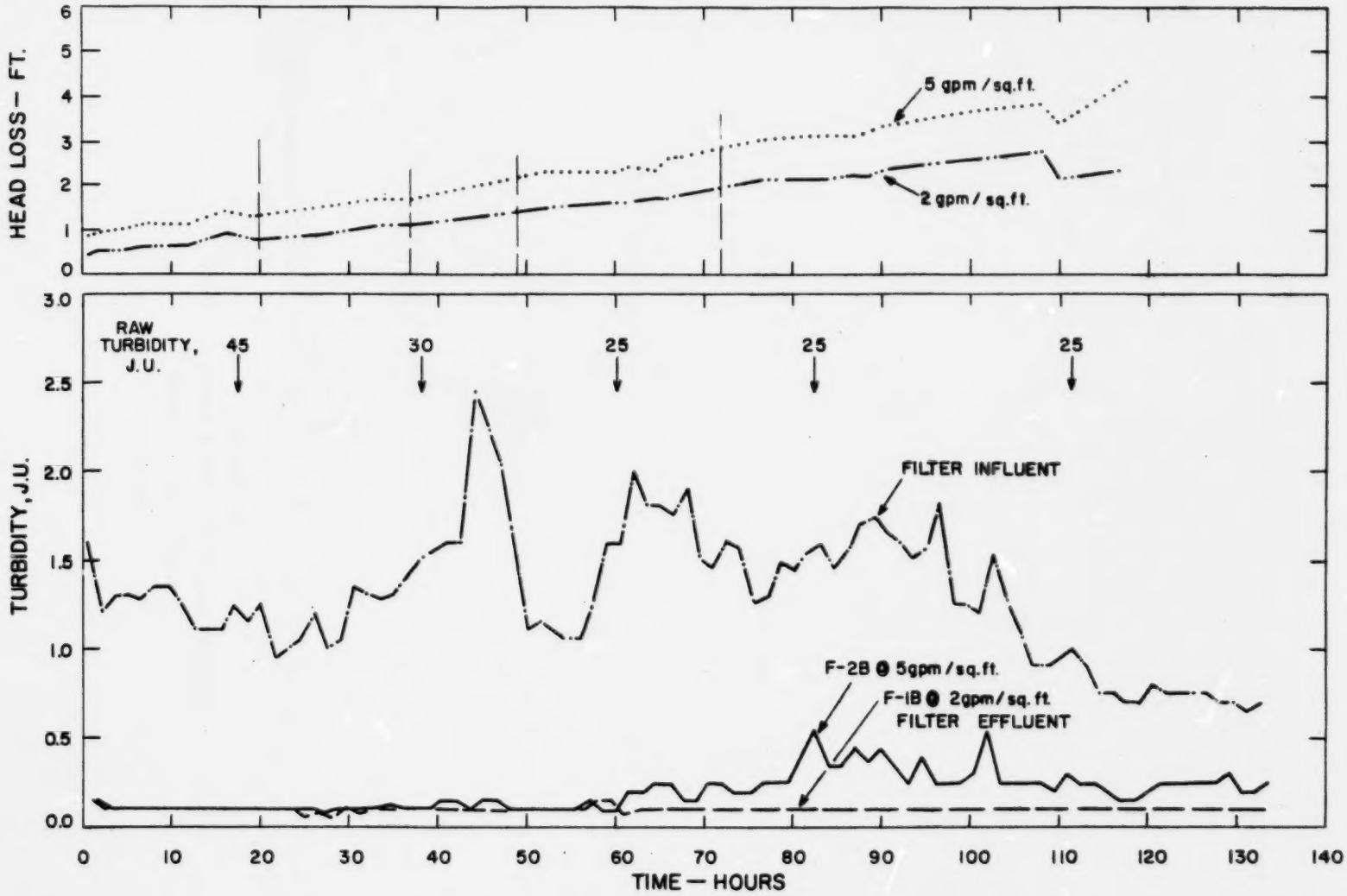
FIGURE 11



TURBIDITY VALUES AT 2 AND 5 gpm/sq.ft. RATES

RUN # 3, 9/3 — 10/59

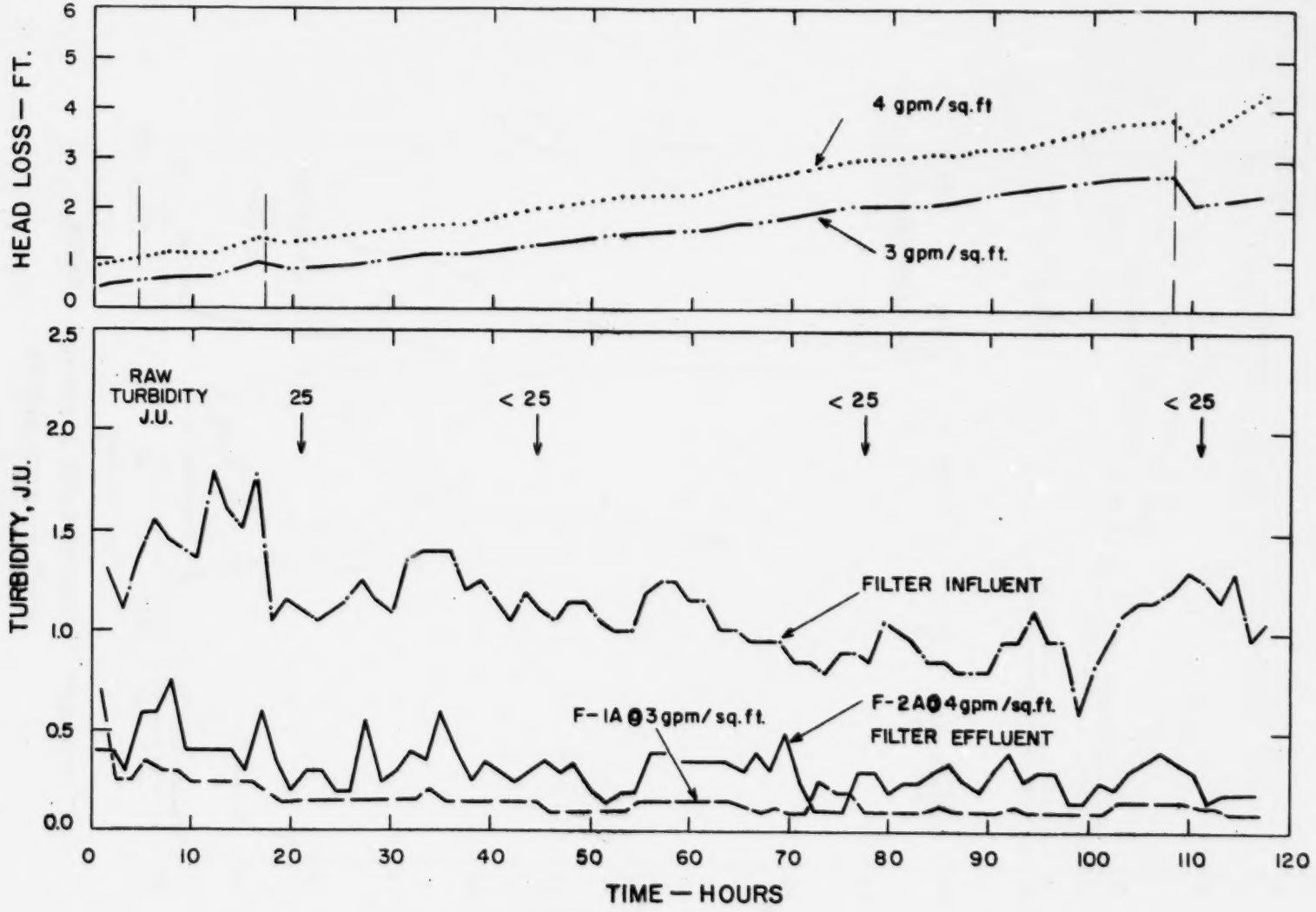
FIGURE 12



TURBIDITY VALUES AT 2 AND 5 gpm/ sq.ft. RATES

RUN #4, 9/11 — 17/59

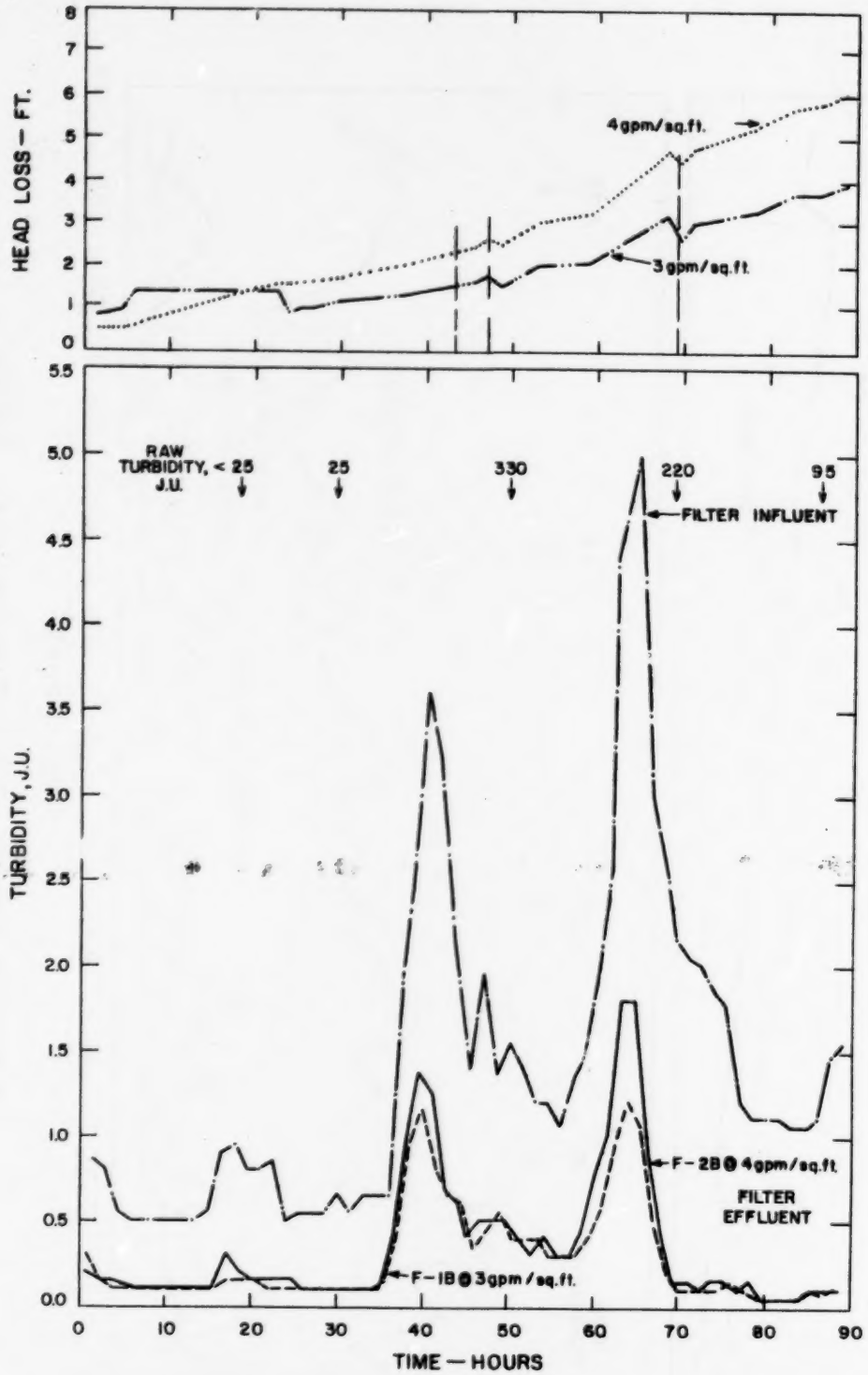
FIGURE 13



TURBIDITY VALUES AT 3 AND 4 gpm/sq.ft. RATES

RUN #5, 9/19 — 25/59

FIGURE 14



TURBIDITY VALUES AT 4 AND 3 gpm/sq.ft. RATES

RUN # 6 — 9/27 — 10/2/59

FIGURE 15

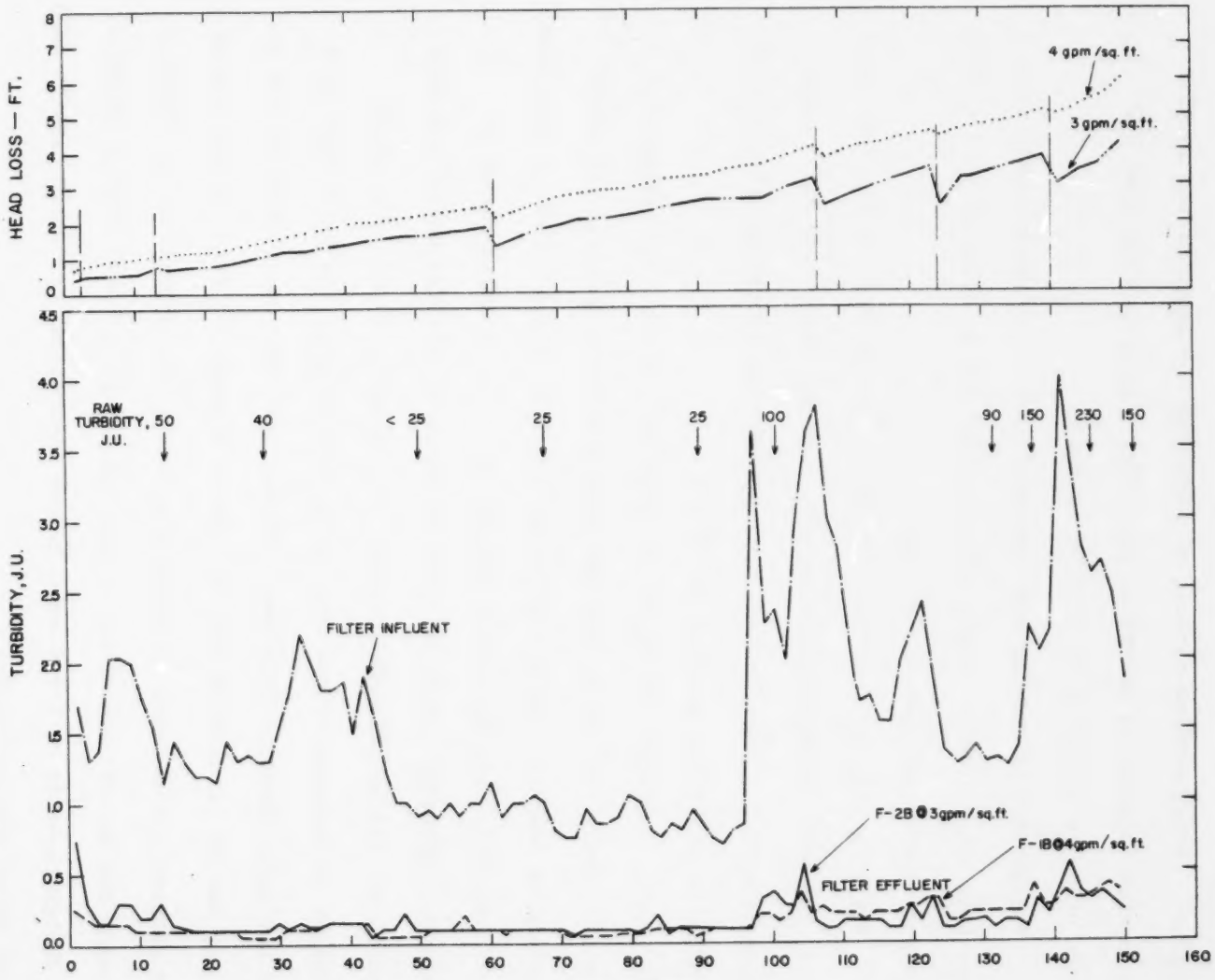
was usually a gradual increase in effluent turbidity for a few hours thereafter. Despite these periods of turbidity the operator was usually able to make adjustments to return the final quality to less than 0.2 Jackson unit, as evidenced at hour 95 in run 3.

The pattern of results was similar in the other three summer runs except that the 4 gpm per square foot rate did not do quite as well as the 3 gpm per square foot rate during run 5.

Starting with run 7 in October and continuing through the fall with run 12, the effluent turbidities at both high and low filter rates were usually below 0.2. When, on one occasion, the raw turbidity went over 700, the effluent turbidity was kept below 1.0.

Winter temperatures caused the sampling lines to the basins and gullet to freeze, so the project was suspended until spring, when runoff and changing temperatures were expected to put an extra stress on the plant.

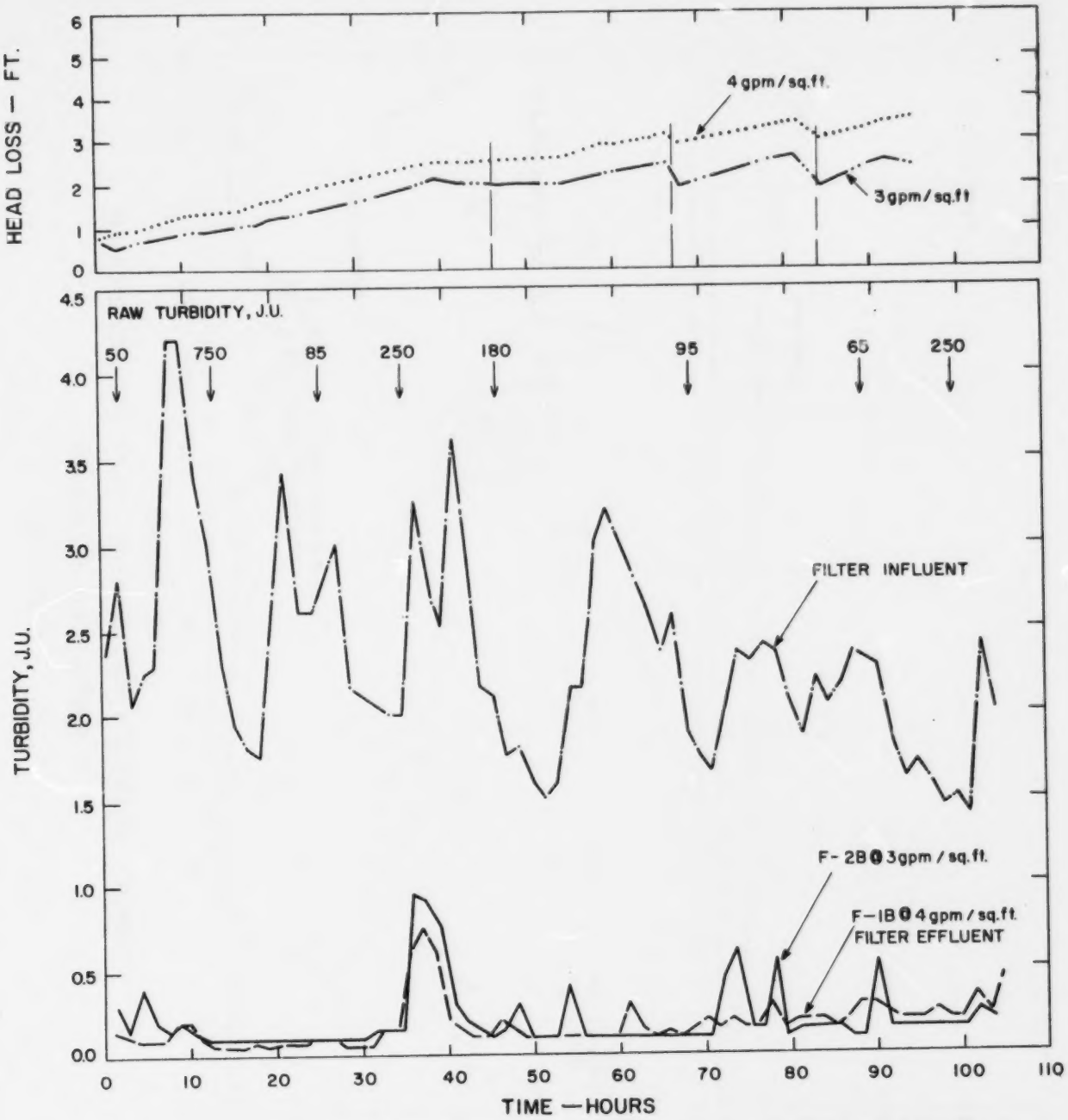
Run 13 in late March 1960 demonstrated that a rapid change in influent temperature caused an upset in the open settling basins and thus degraded the filter effluent quality. There was no rise in raw water turbidity so temperature and thus short circuiting in the basin must have been the major factor. This condition may have been accentuated by the use of only two of the three basins in runs 13 through 30; that is, the basins were purposely overloaded to simulate possible future conditions. Table 3 presents the percent underload or overload for all 30 test runs as based on the design capacity of 1 mgd and a 6-hour theoretical detention time in each of the three parallel basins.



TURBIDITY VALUES AT 3 AND 4 gpm/ sq.ft. RATE AND ONLY 2 BASINS

RUN# 7, 10/3 — 11/59

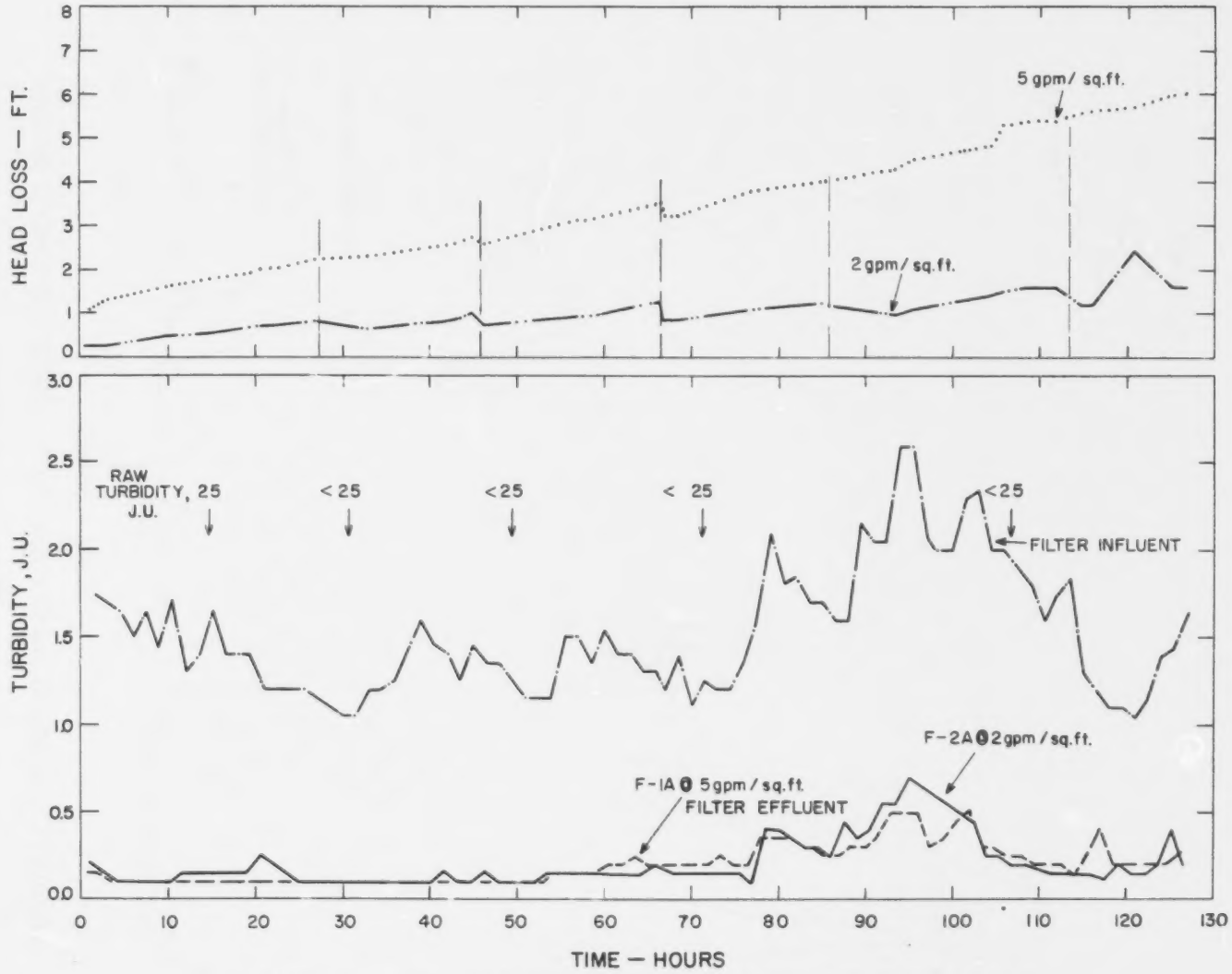
FIGURE 16



TURBIDITY VALUES AT 3 AND 4 gpm/sq. ft. RATE AND ONLY 2 BASINS

RUN # 8, 10/13—18/59

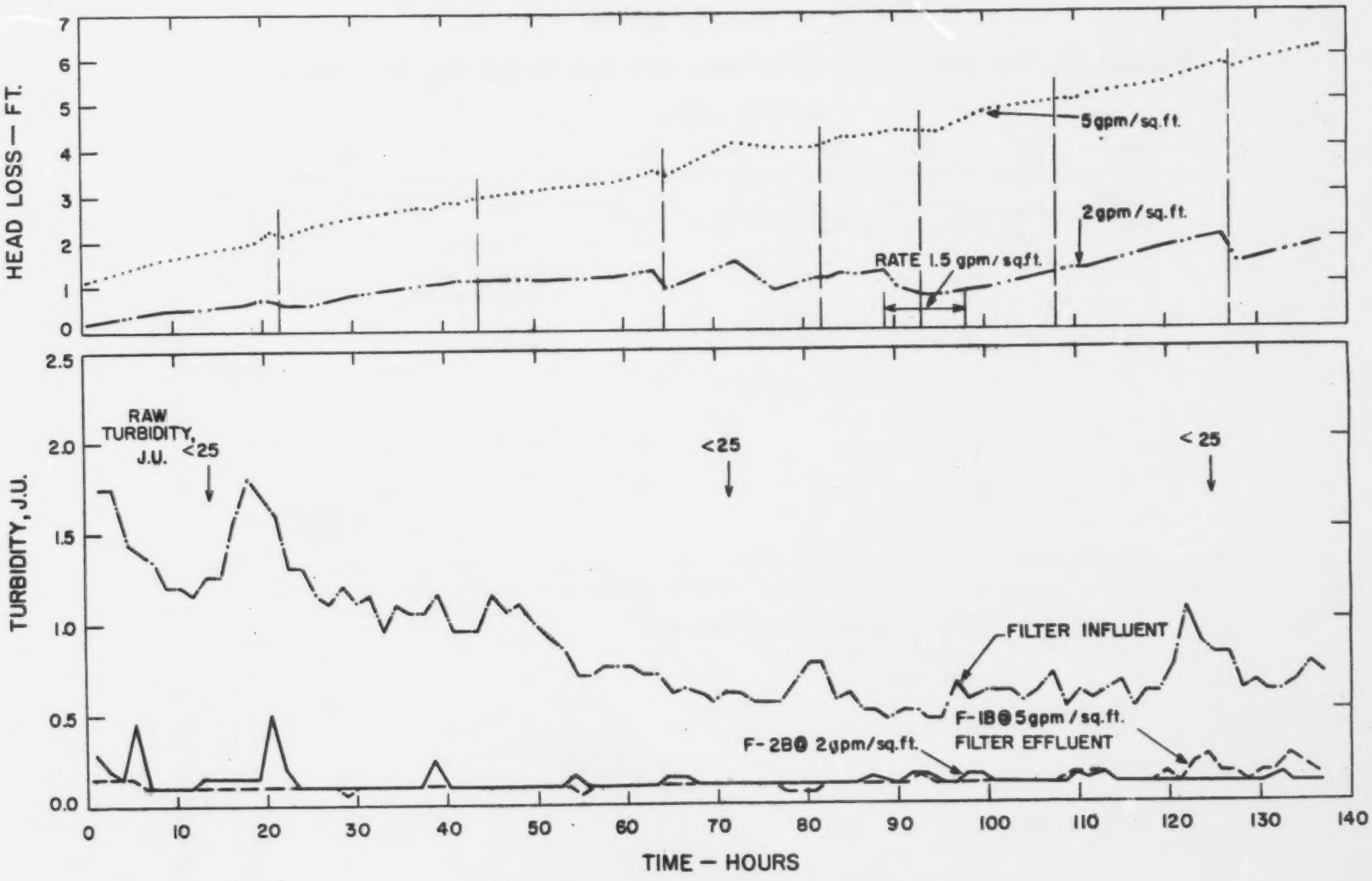
FIGURE 17



TURBIDITY VALUES AT 5 AND 2 gpm/sq.ft. RATE AND ONLY 2 BASINS

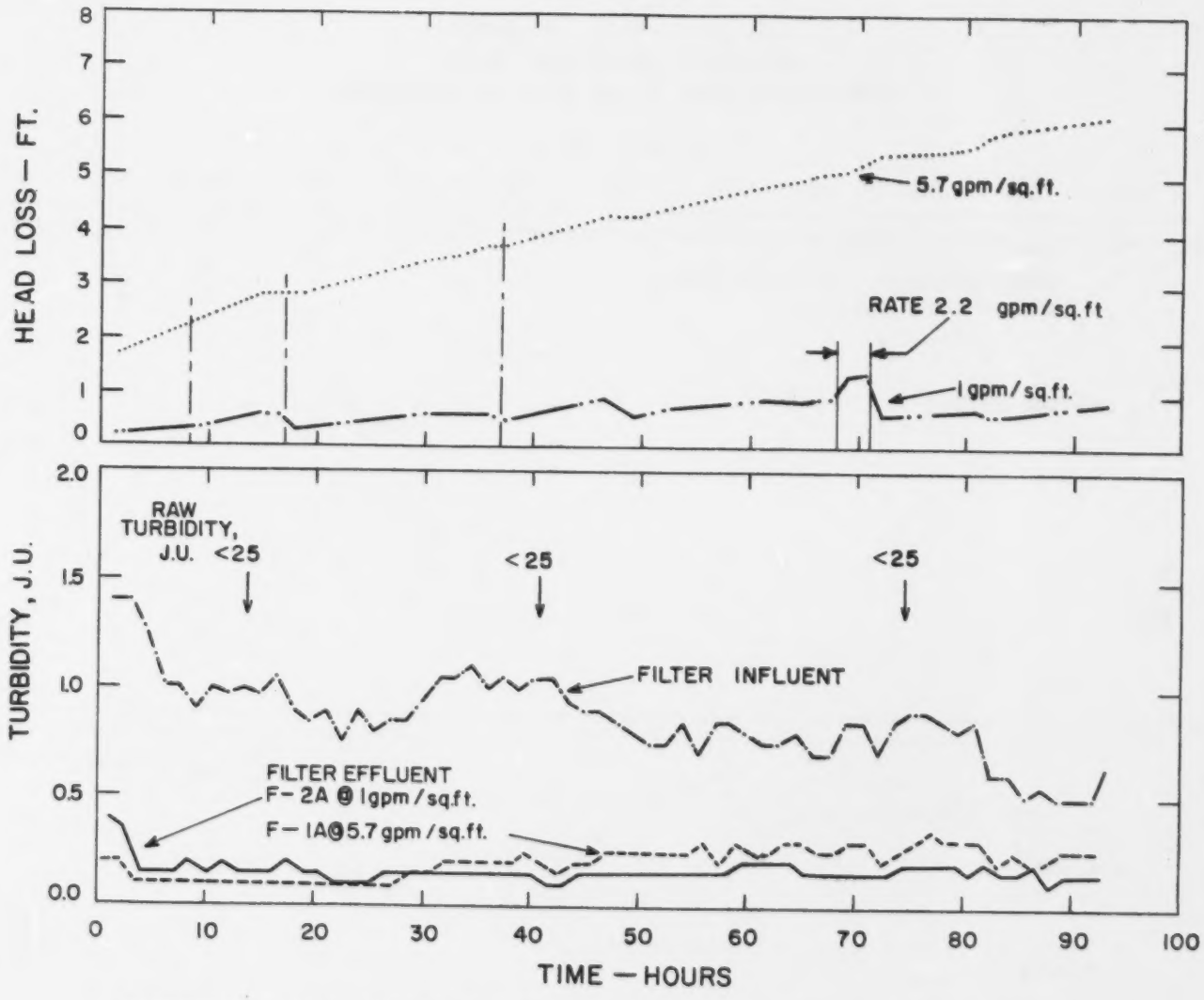
RUN# 9 , 10/27—11/2/59

FIGURE 18



TURBIDITY VALUES AT 2 AND 5 gpm/sq.ft.
RATE AND ONLY 2 BASINS
RUN# 10, 11/3 — 10/59

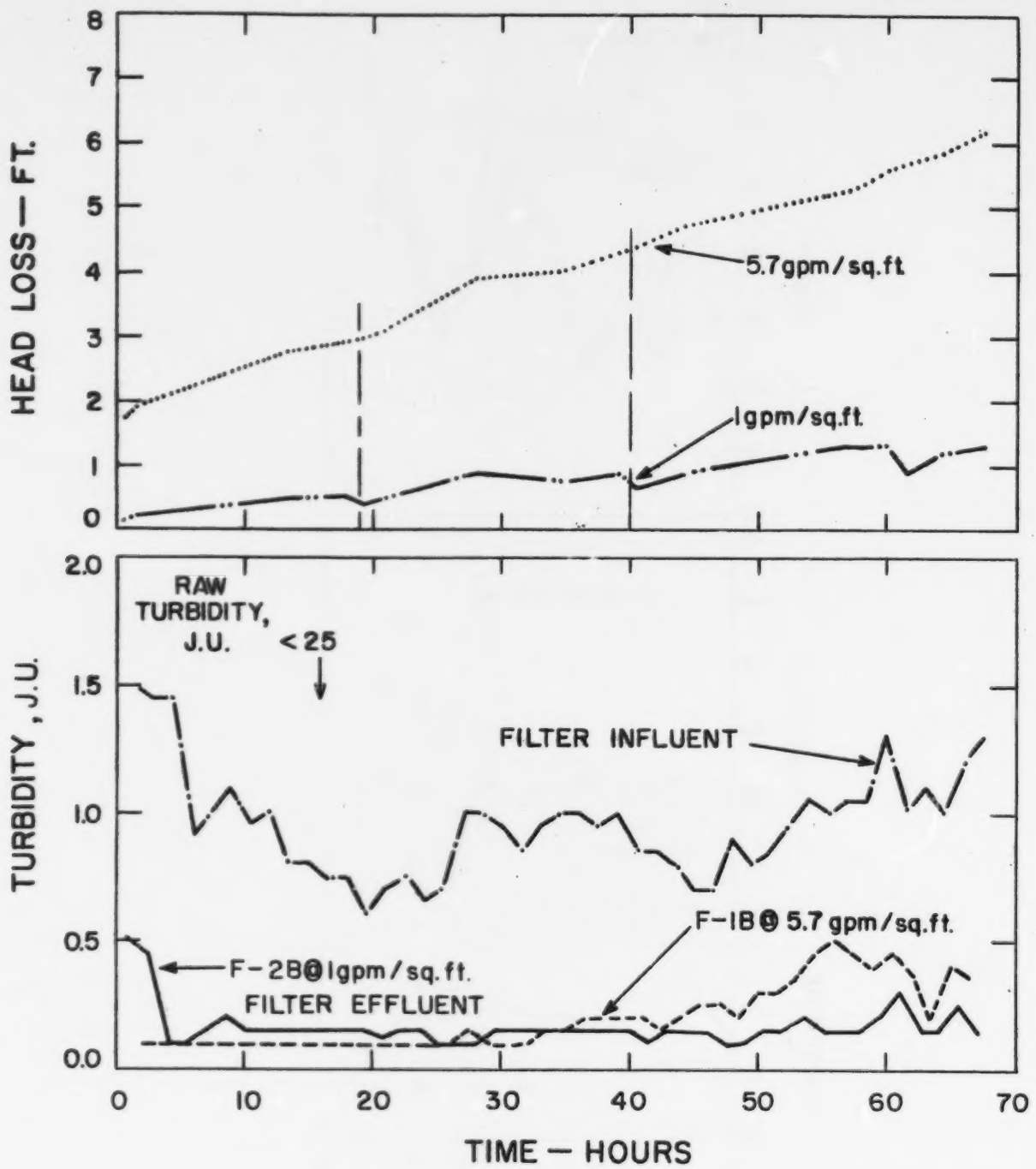
FIGURE 19



TURBIDITY VALUES AT 5.74 AND 1gpm/sq.ft. RATE AND ONLY 2 BASINS

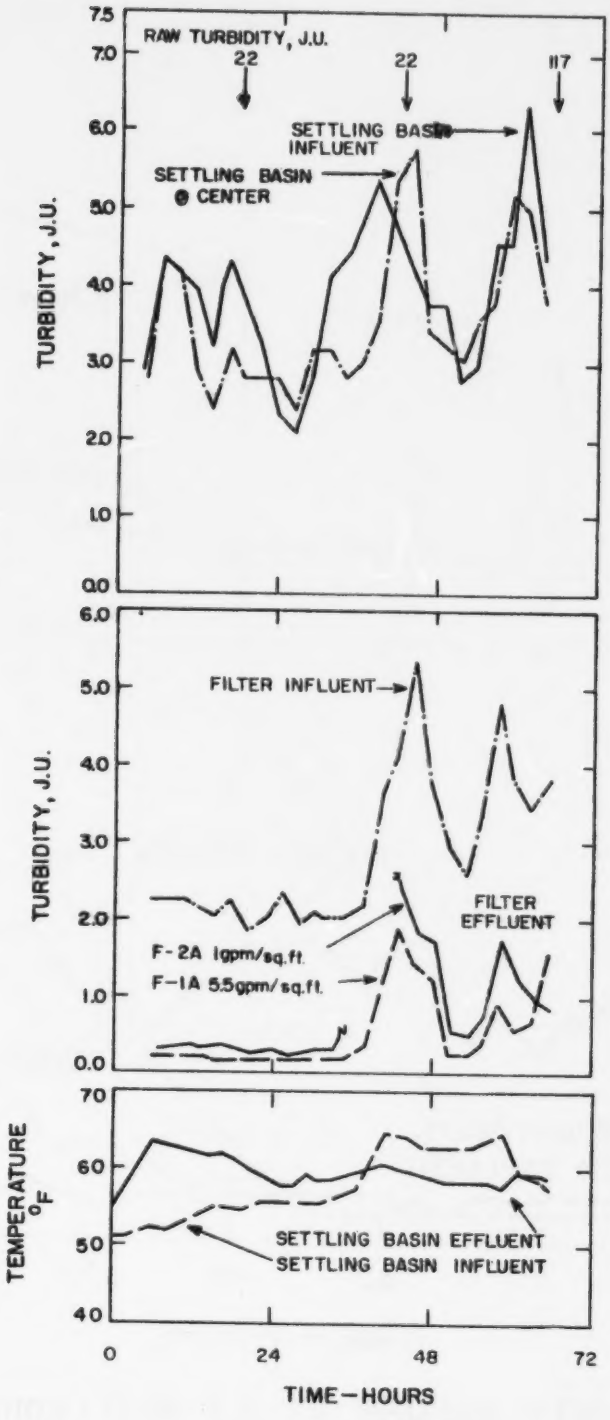
RUN# 11, 11/11 — 16/59

FIGURE 20



TURBIDITY VALUES AT 5.7 AND 1 gpm/sq.ft. RATE AND ONLY 2 BASINS
RUN# 12, 11/17 — 20/59

FIGURE 21



TURBIDITY VALUES FOR
1 AND 5.5 gpm/sq.ft. RATES
USING ONLY 2 BASINS
RUN# 13, 3/28-30/60

FIGURE 22

Table 3. HYDRAULIC LOADING OF SETTLING BASINS DURING TEST RUNS[a]

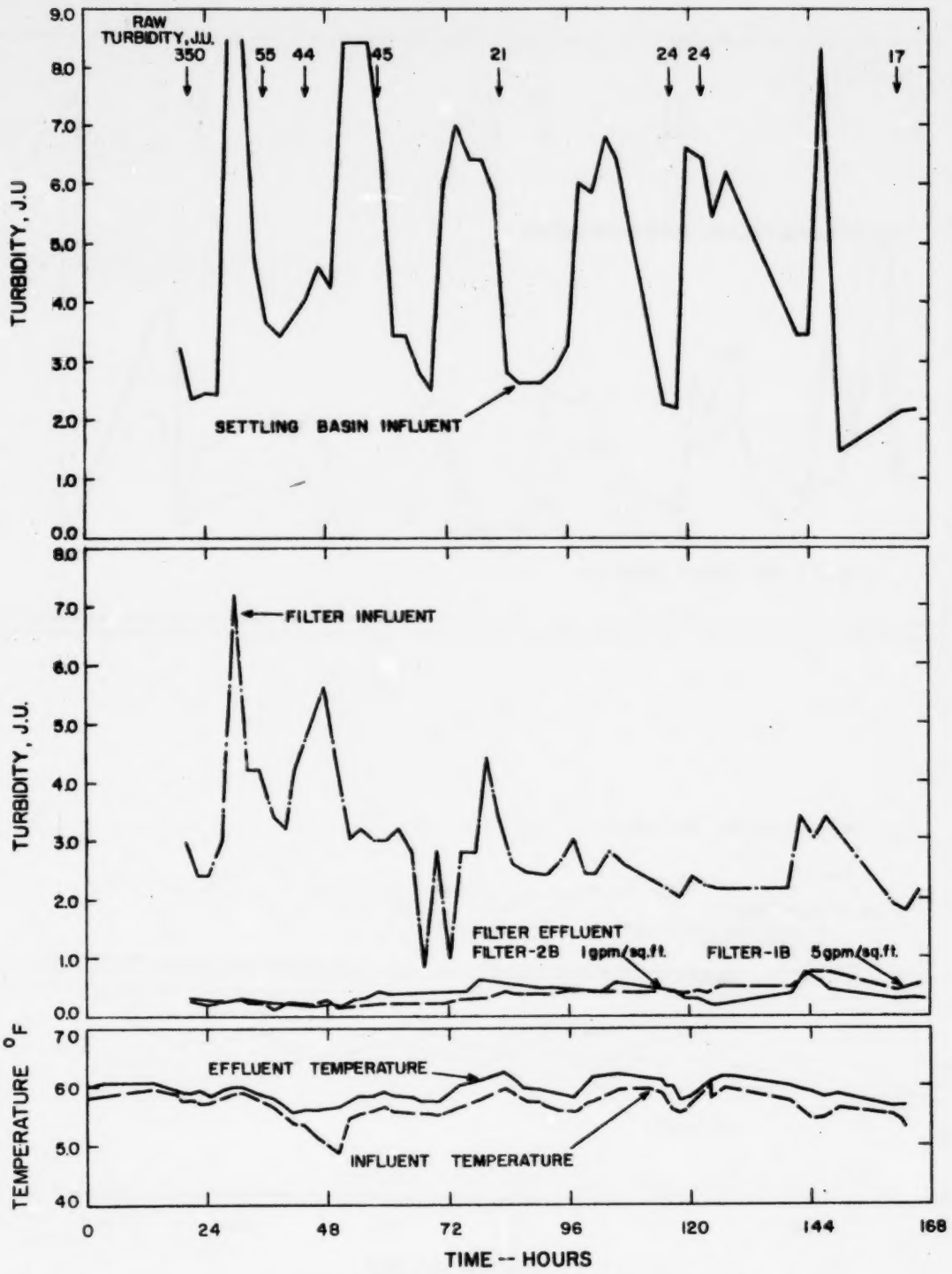
Date started	Run no.	Hours run	Water production, gal	Flow rate, mgd	Percent underload(-) or overload(+)	Detention time, hr
8/25/59	1	91.0	10,430,000	2.75	-8.3	6.6
8/29/59	2	81.0	9,210,000	2.73	-9.0	6.6
9/3/59	3	144.0	16,320,000	2.72	-9.3	6.6
9/11/59	4	133.5	15,130,000	2.72	-9.3	6.6
9/19/59	5	117.5	13,320,000	2.72	-9.3	6.6
9/27/59	6	89.0	10,080,000	2.72	-9.3	6.6
10/3/59	7	150.0	17,000,000	2.72	-9.3	6.6
10/13/59	8	105.5	11,960,000	2.72	-9.3	6.6
10/27/59	9	127.0	13,992,200	2.64	-12.0	6.8
11/3/59	10	137.0	14,247,000	2.50	-16.7	7.2
11/11/59	11	93.0	10,140,000	2.62	-12.7	6.9
11/17/59	12	67.5	7,489,600	2.66	-11.3	6.8
3/28/60	13	61.5	6,039,000	2.35	+18	5.1
4/5/60	14	115	10,800,000	2.26	+13	5.3
4/12/60	15	123	13,280,000	2.59	+30	4.6
4/19/60	16	93.5	9,728,000	2.53	+26	4.7
4/26/60	17	100	11,372,000	2.73	+36	4.4
11/8/60	18	85	8,340,000	2.35	+18	5.1
11/14/60	19	88	8,160,000	2.23	+12	5.4
11/28/60	20	83	7,700,000	2.23	+12	5.4
12/5/60	21	90	8,542,000	2.29	+14	5.2
12/13/60	22	65	6,079,050	2.24	+12	5.4
1/3/61	23	60	5,554,000	2.22	+11	5.4
1/9/61	24	89.5	8,655,000	2.32	+16	5.2
1/16/61	25	96	8,700,000	2.17	+8	5.5
1/30/61	26	81.5	7,700,000	2.27	+14	5.3
2/6/61	27	68	6,450,000	2.28	+14	5.3
2/13/61	28	99	9,600,000	2.33	+16	5.2
2/20/61	29	71	6,775,000	2.29	+14	5.2
4/17/61	30	163	24,057,000	3.54	+77	3.4

a-Plant design capacity: 1 mgd on each of three settling basins.
Test conditions: 3 basins used for first 12 runs, 2 basins used for last 18 runs.

Even though the basins were hydraulically overloaded during run 14, the operator was able to handle raw water turbidities as high as 50 to 350 regardless of filter rate. The other three runs during the spring of 1960 produced excellent water except for one 7-hour period in run 16. The results for the basin influent (the top line of each figure) indicate there was usually a daily increase in turbidity at this location. It was assumed that raw water temperature (plotted at the bottom) rather than raw turbidity usually caused this daily rise. Fortunately, the two basins were able to handle these fluctuations without overloading the filter. As indicated before, this was not the case when the rise was due to an increase in raw water turbidity. Of course, sudden changes in both temperature and turbidity probably compound the problem of adequate coagulation, as illustrated at hour 52, run 18 (Figure 27) in the fall of 1960. Filtration rates, however, did not make much difference in quality. In fact, as in the fall of 1959, excellent water was made at all rates, 1 through 5.

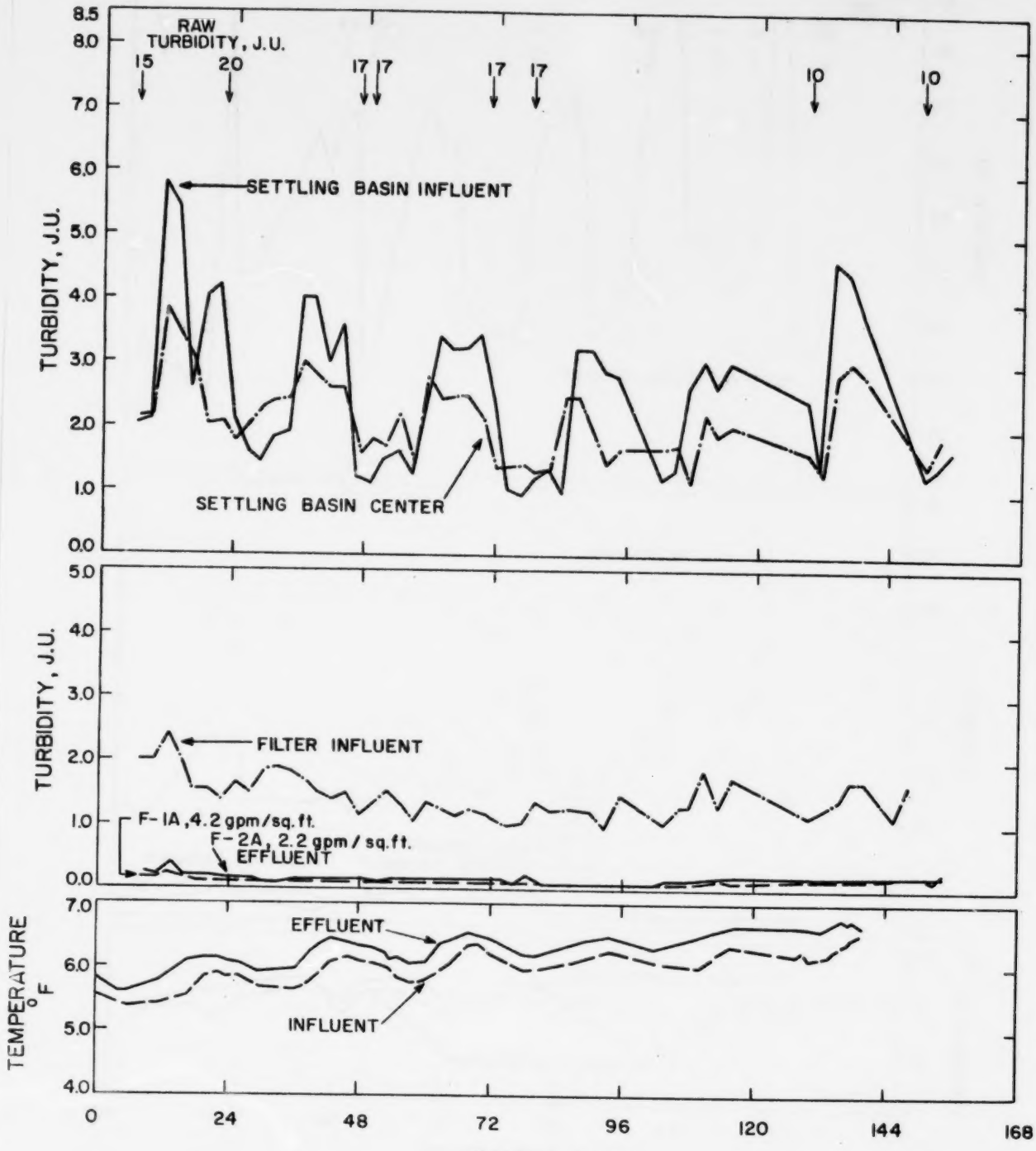
By mid-December and through the winter, there was usually a slight deterioration of quality in the effluent from the high-rate filter at the point where the headloss approached 6 feet. This was not always true but it happened during runs 22, 23, 24, 26, and 28. Runs 27 and 29 probably should have been stopped when both filters started producing bad water. Actually run 29 was stopped when a breakthrough occurred for the second time. Postchlorination was, of course, adequate to protect against any possible trouble from such waters.

A special run, 30 (Figure 39), was conducted in the spring of 1961 to further overload two settling basins and also to see how well three filters,



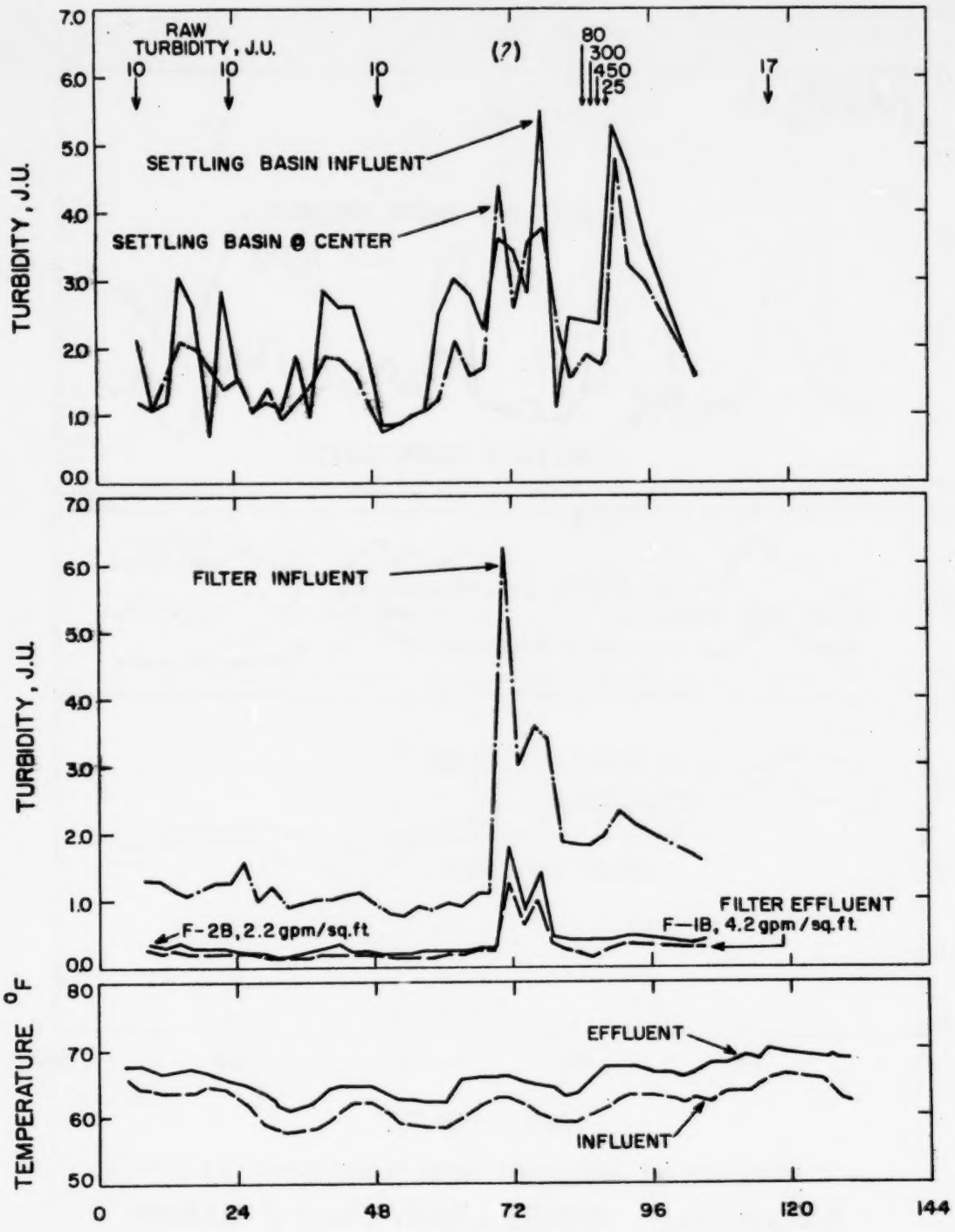
TURBIDITY VALUES FOR 1 AND 5gpm/sq.ft.
RATE USING ONLY 2 BASINS
RUN# 14, 4/5 — 11/60

FIGURE 23



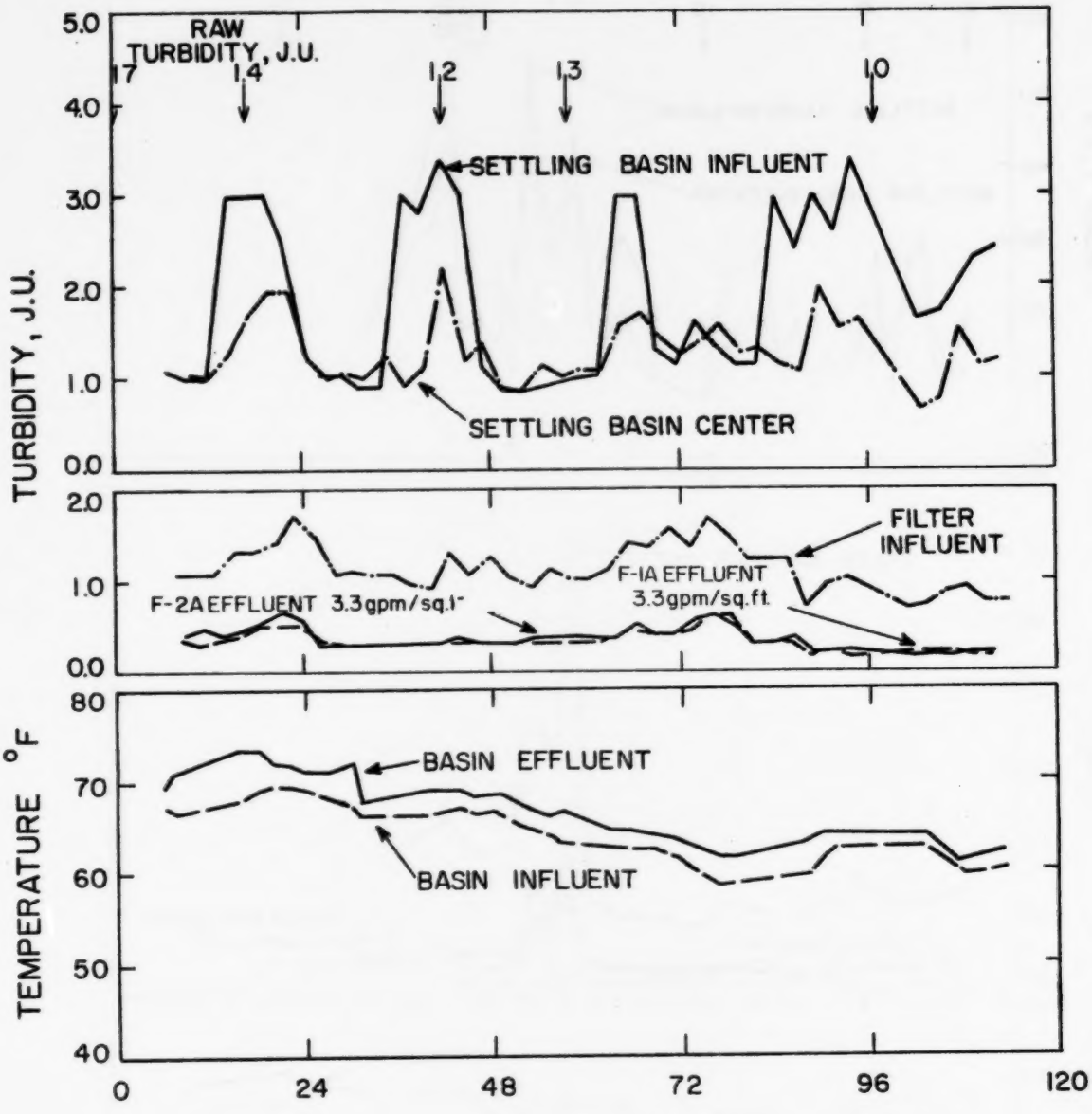
TURBIDITY VALUES FOR 2.2 AND 4.2 gpm/ sq.ft.
RATES USING ONLY 2 BASINS
RUN# 15, 4/12 — 18/60

FIGURE 24



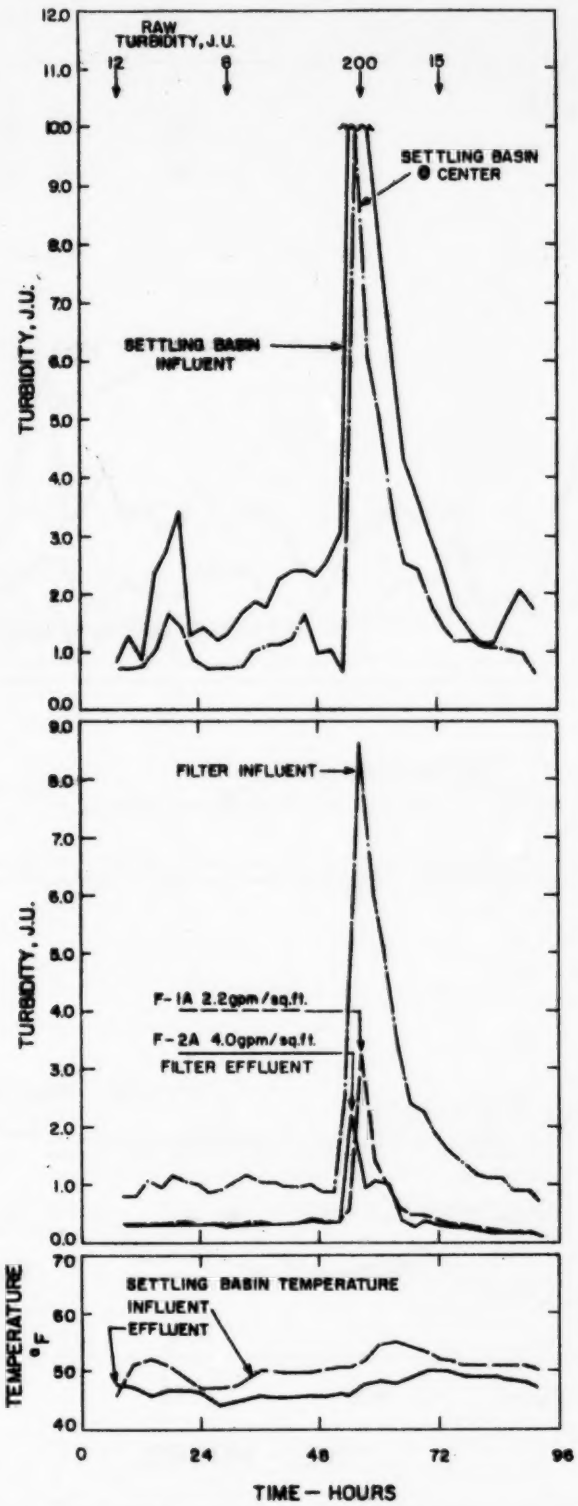
TURBIDITY VALUES FOR 4.2 AND 2.2 gpm/sq.ft.
RATES USING ONLY 2 BASINS
RUN# 16, 4/18 — 23/60

FIGURE 25

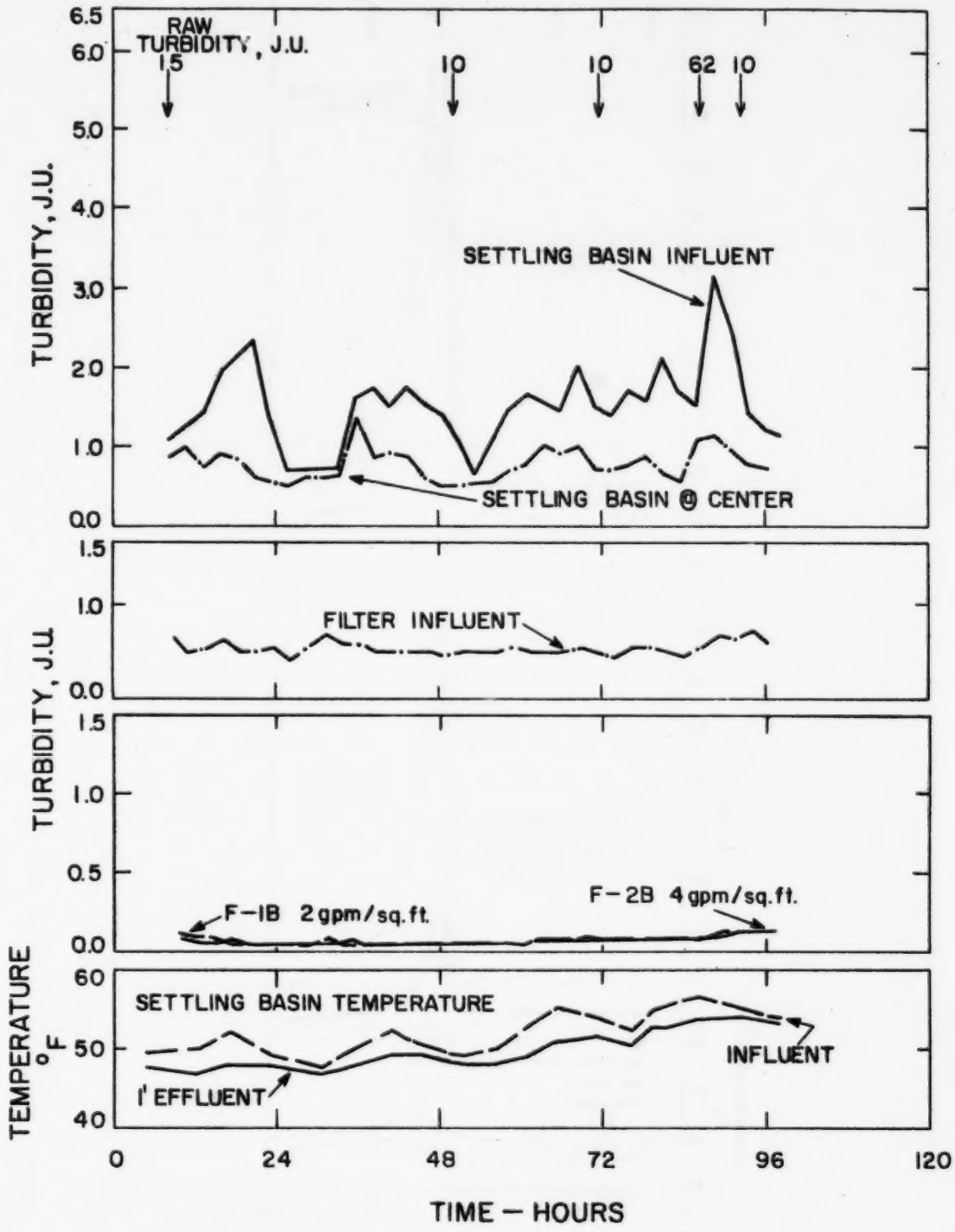


TURBIDITY VALUES FOR 2 FILTERS AT
3.3 gpm/sq.ft. RATES USING ONLY 2 BASINS
RUN# 17, 4/26—30/60

FIGURE 26

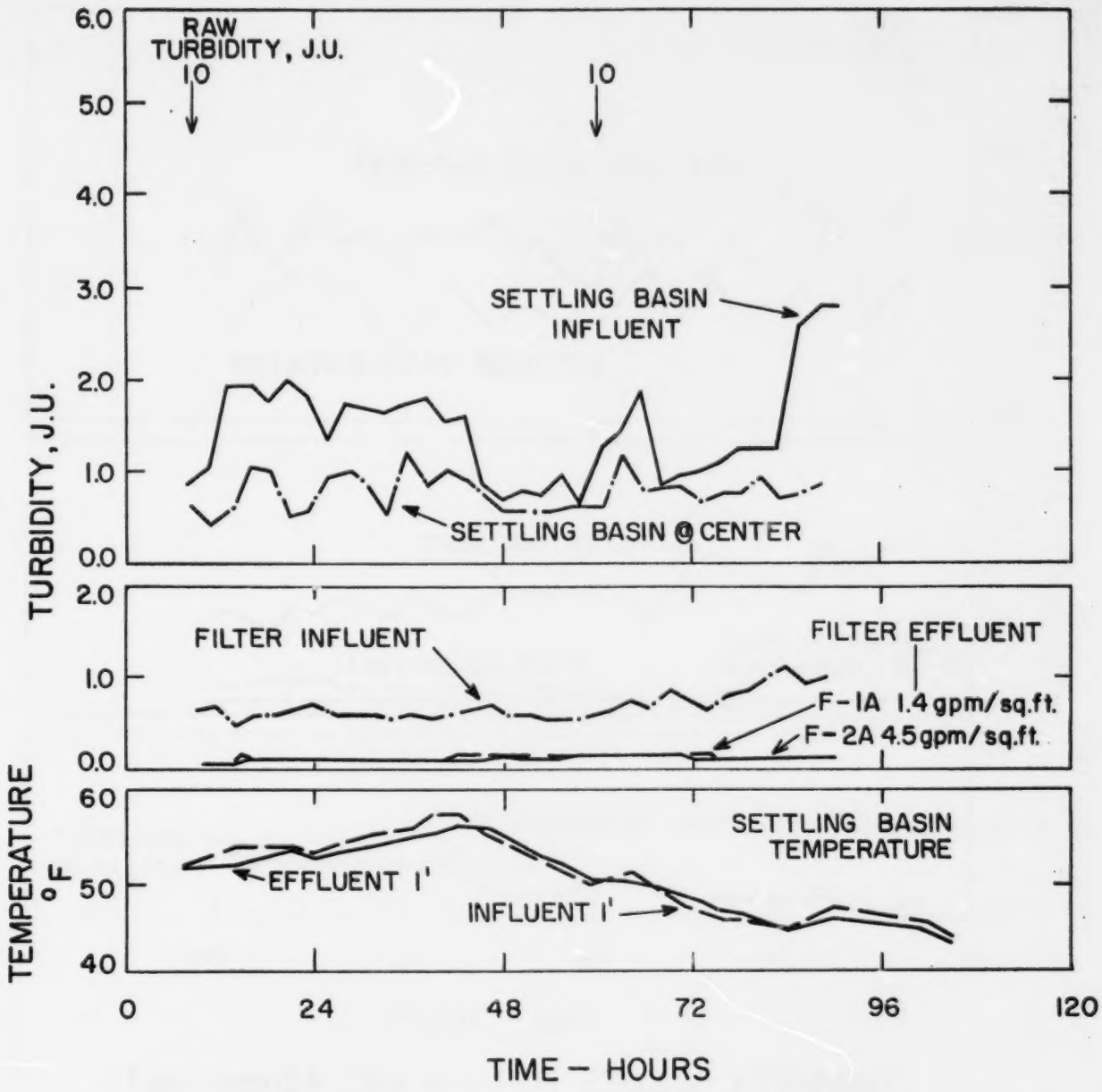


TURBIDITY VALUES FOR 2.2 AND 4.0 gpm/sq.ft.
RATES USING ONLY 2 BASINS
RUN #18, 11/8 — 11/60
FIGURE 27



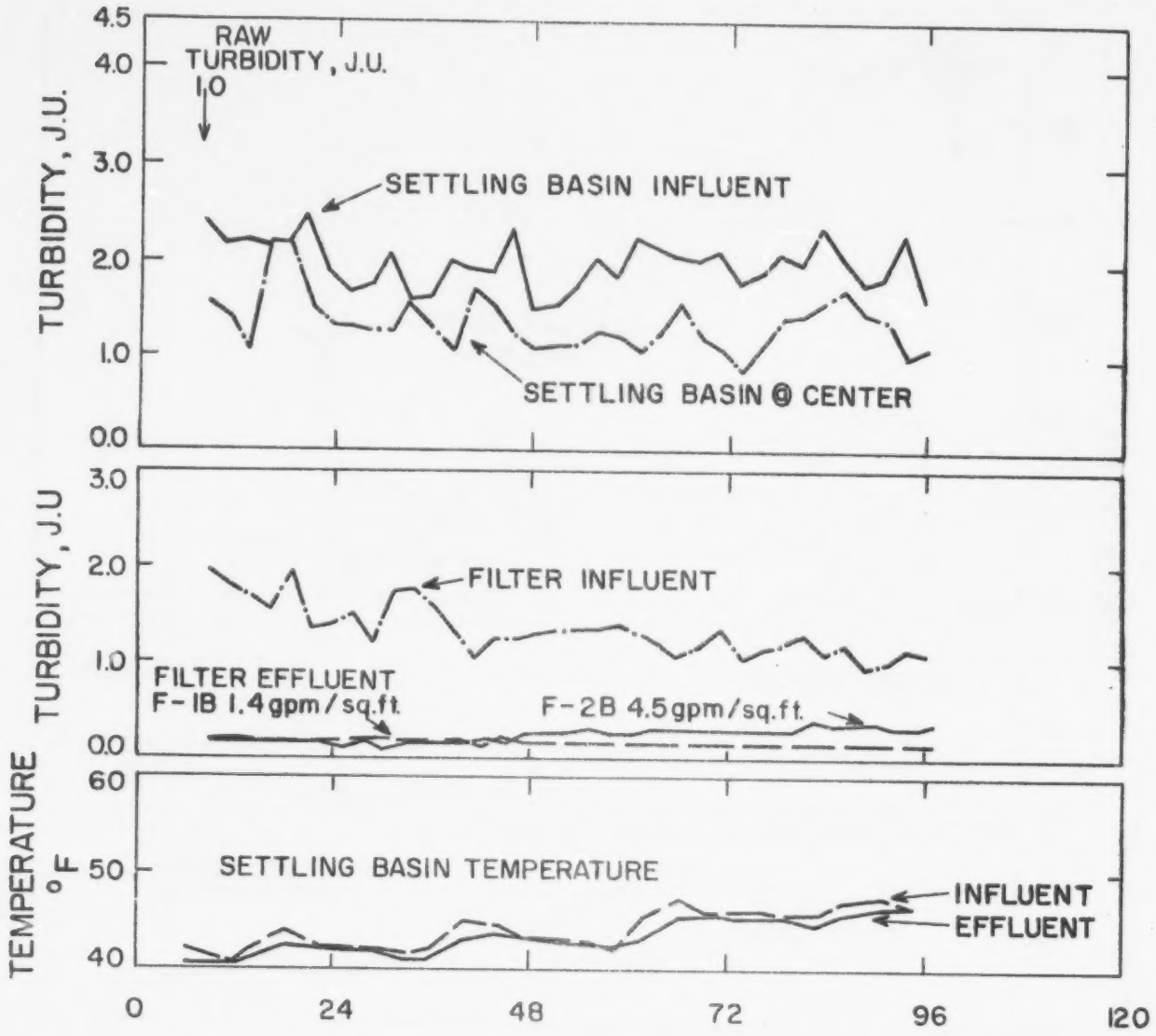
TURBIDITY VALUES FOR 2 AND 4 gpm/sq. ft.
RATES USING ONLY 2 BASINS
RUN# 19, 11/14 — 18/60

FIGURE 28



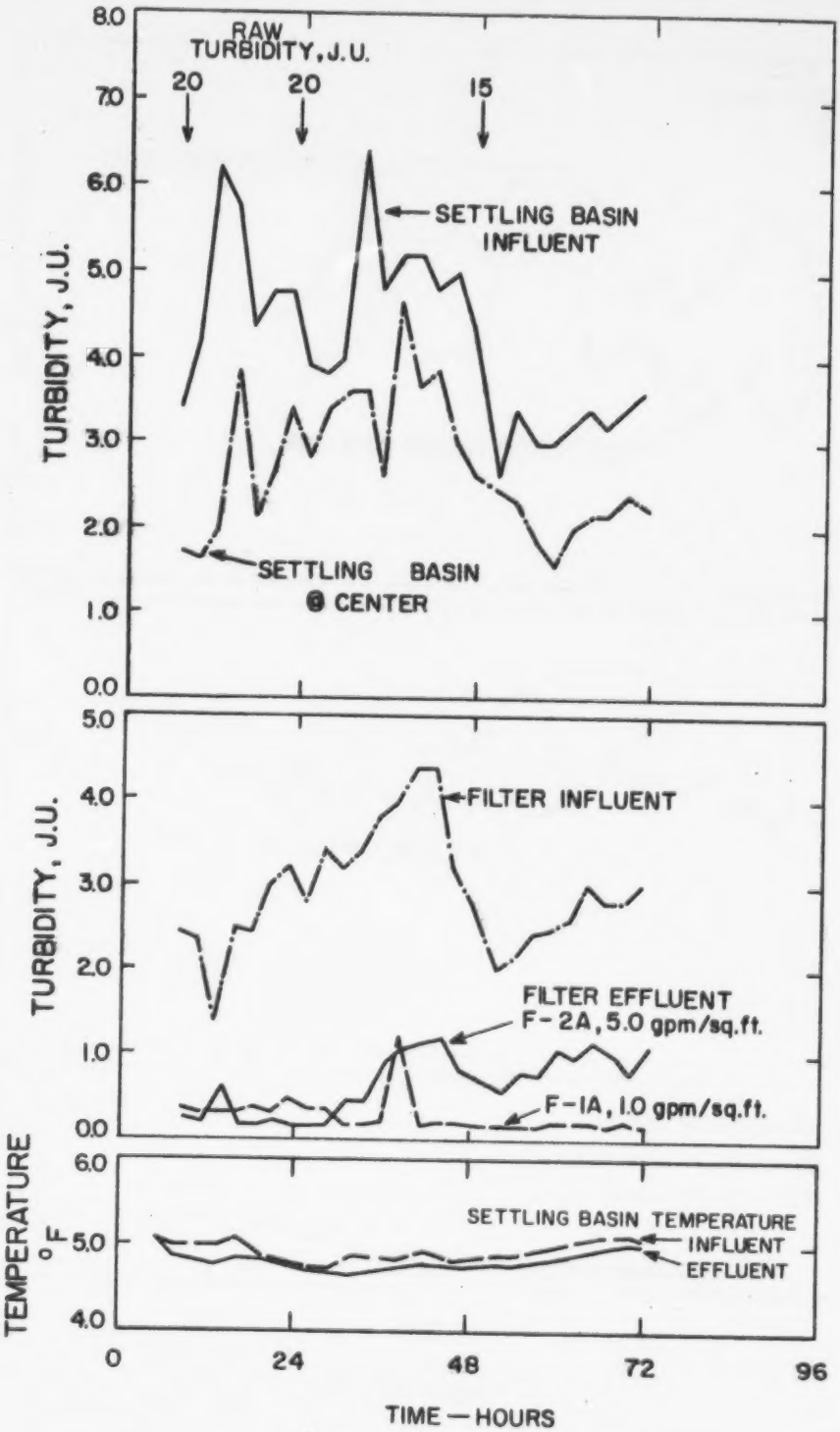
TURBIDITY VALUES FOR 1.4 AND 4.5 gpm/sq.ft.
RATES USING ONLY 2 BASINS
RUN# 20, 11/28 -- 12/2/60

FIGURE 29



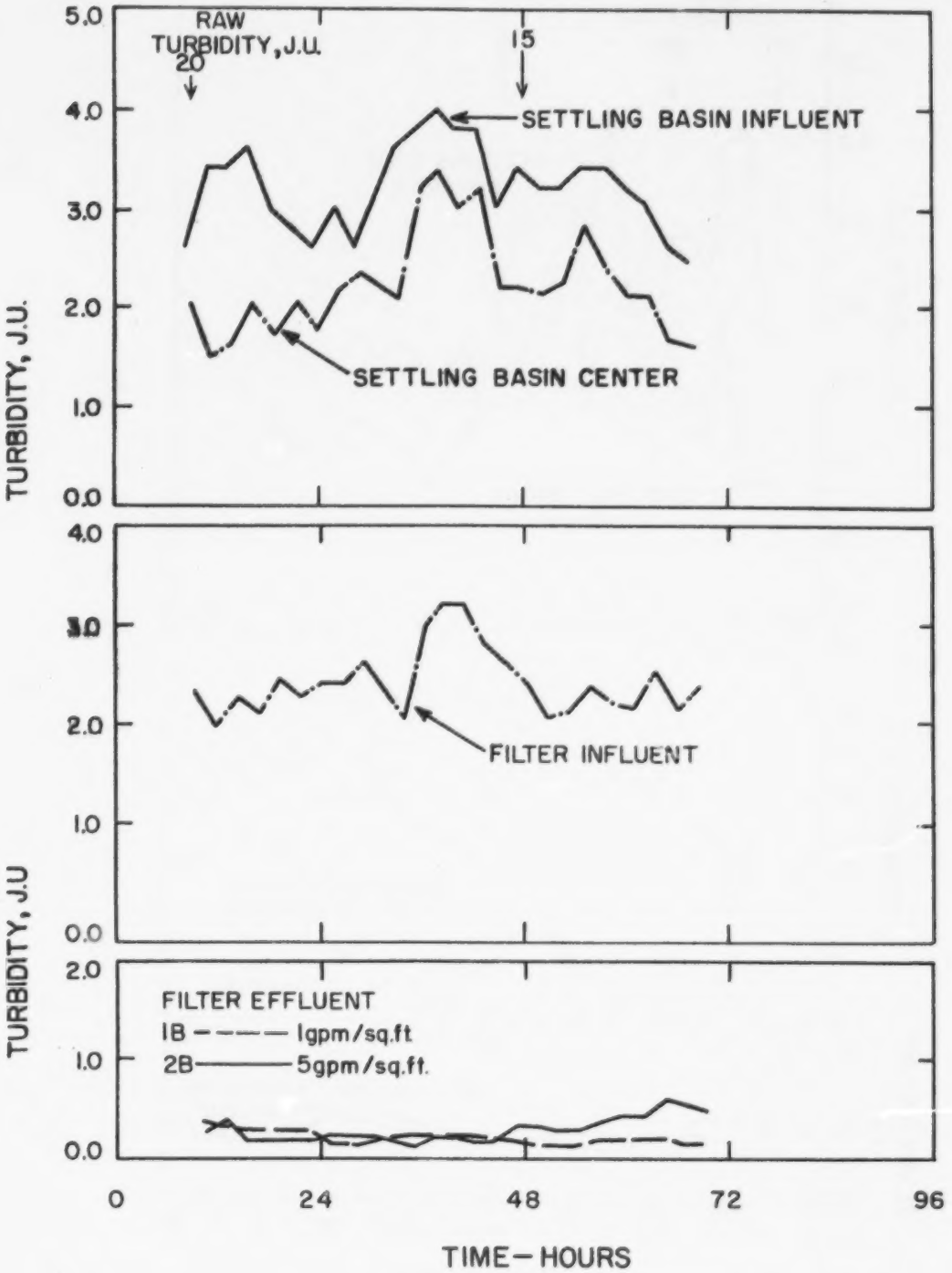
TURBIDITY VALUES FOR 1.4 AND 4.5 gpm/sq.ft.
RATES USING ONLY 2 BASINS
RUN# 21, 12/5 — 9/60

FIGURE 30



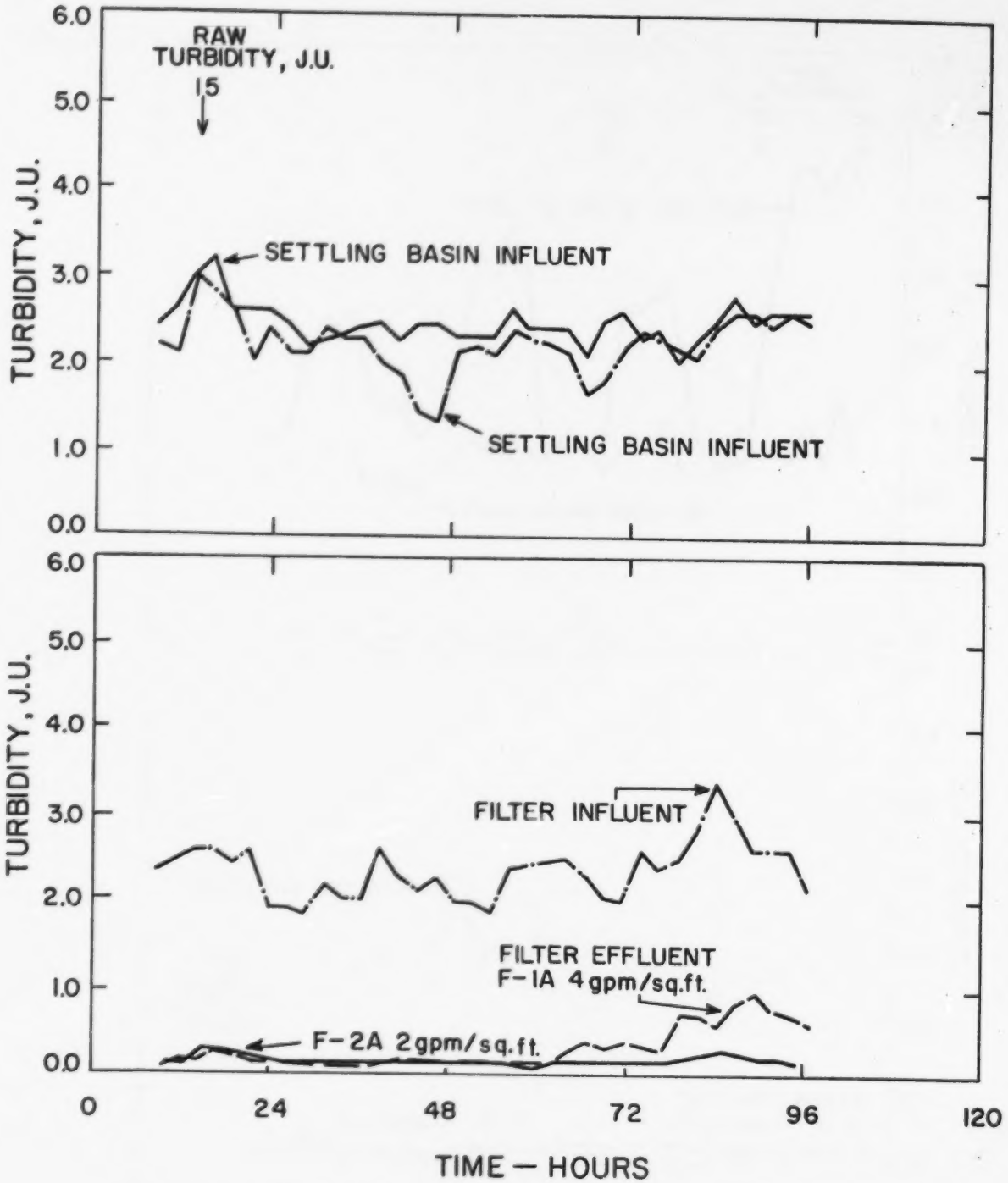
TURBIDITY VALUES FOR 2.2 AND 4.0 gpm/sq.ft.
RATES USING ONLY 2 BASINS
RUN # 22 11/8 — 11/60

FIGURE 31



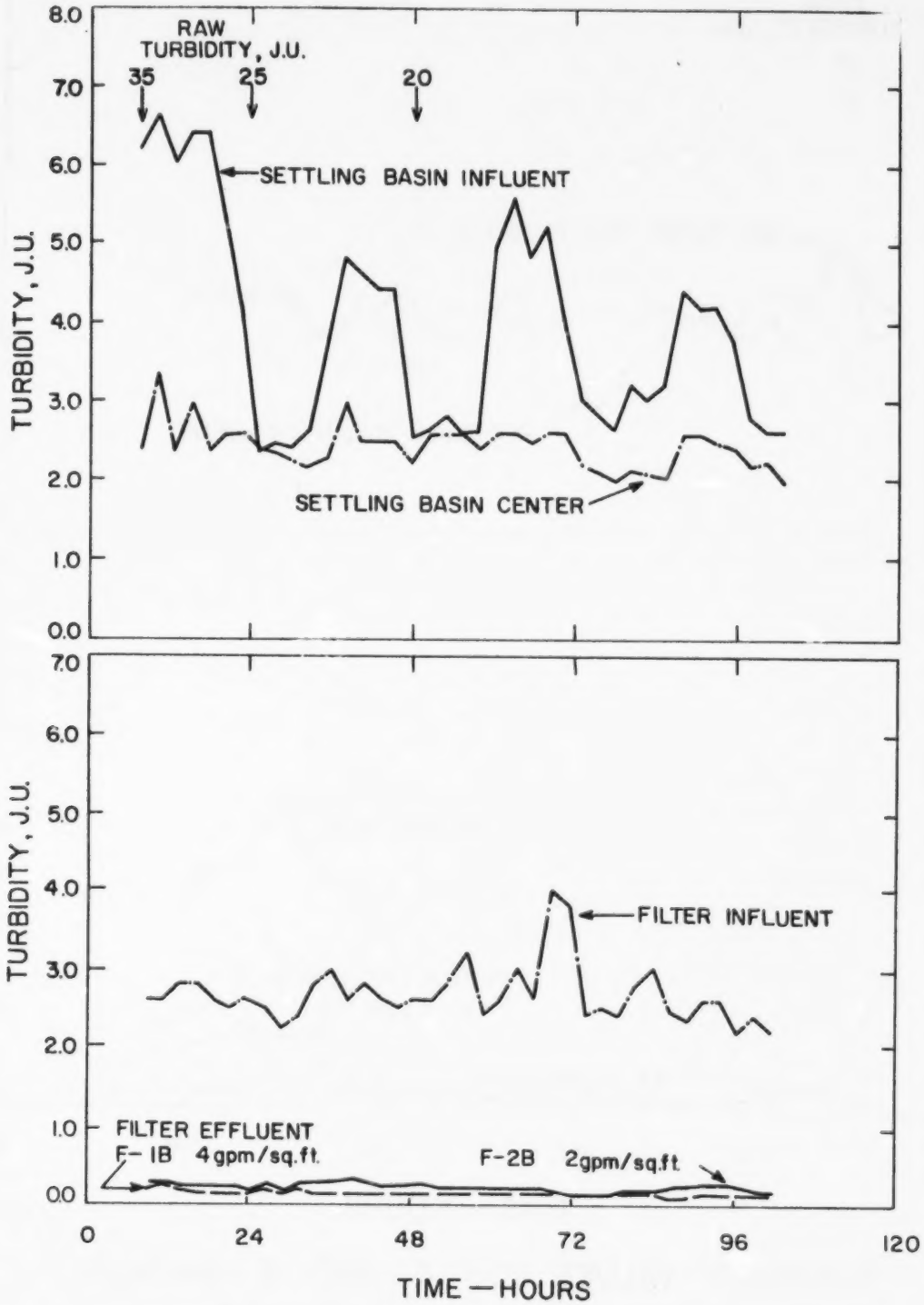
TURBIDITY VALUES FOR 1 AND 5 gpm/sq.ft.
RATES USING ONLY 2 BASINS
RUN 23 1/3 — 5/61

FIGURE 32



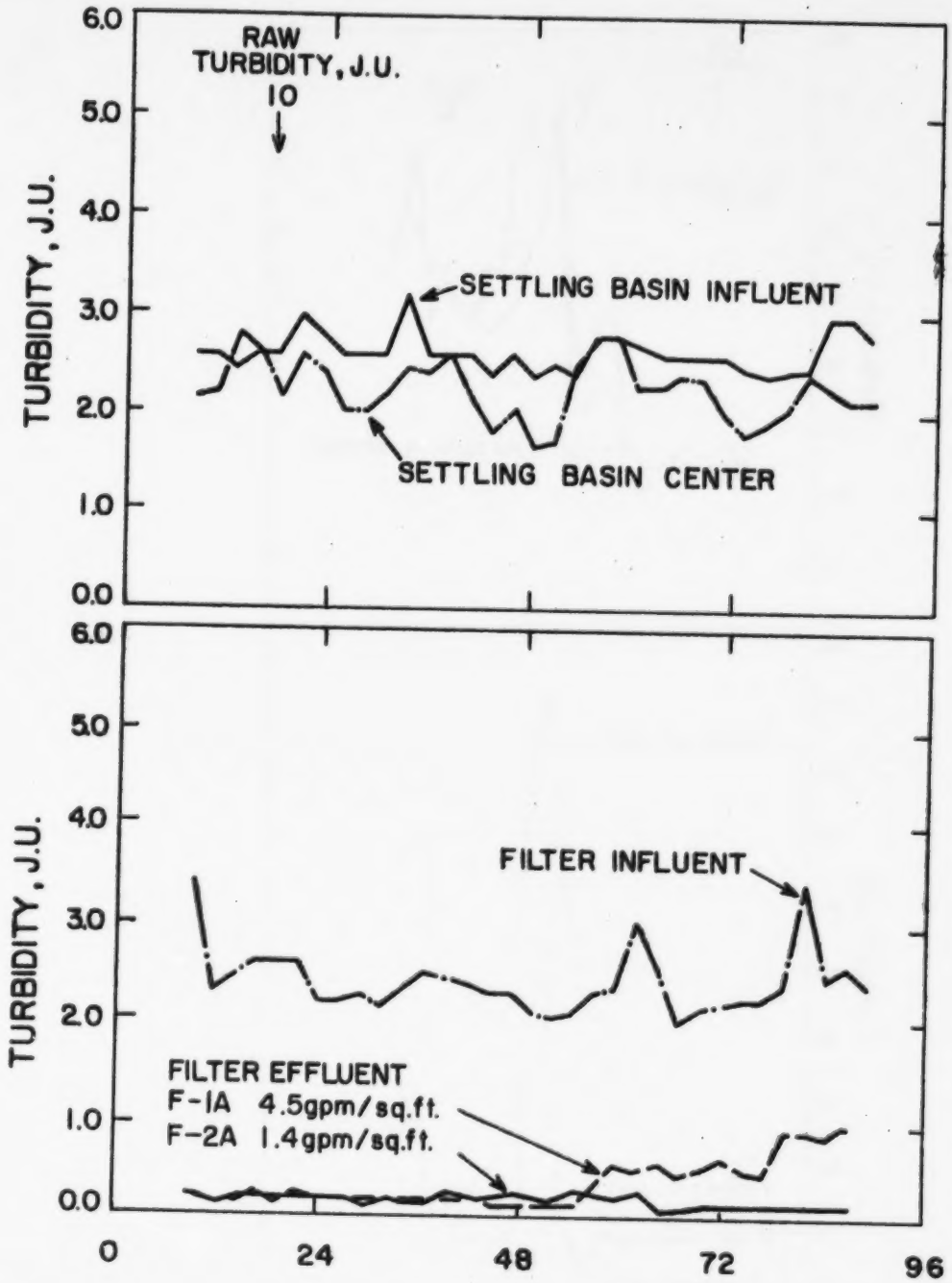
TURBIDITY VALUES FOR 4 AND 2 gpm/sq.ft.
RATES USING ONLY 2 BASINS
RUN# 24, 1/9 — 13/61

FIGURE 33

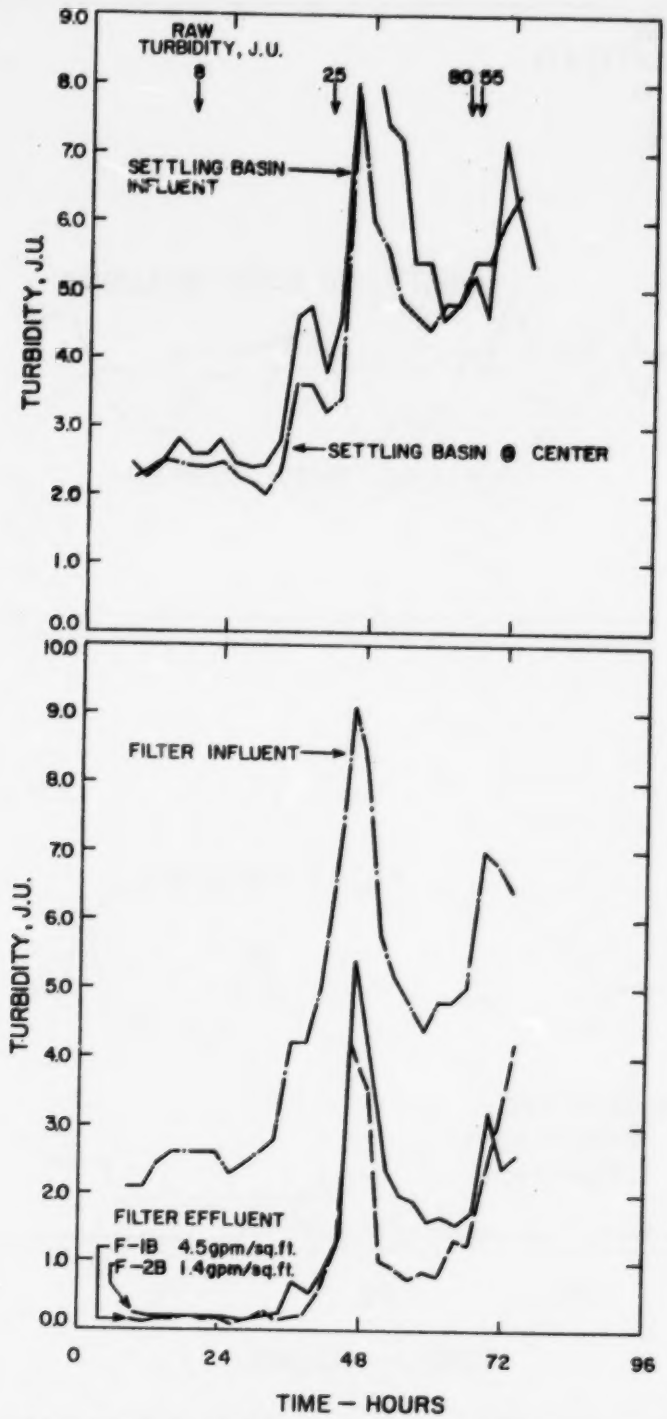


TURBIDITY VALUES FOR 4 AND 2 gpm/sq.ft.
RATES USING ONLY 2 BASINS
RUN #25, 1/16 — 20/61

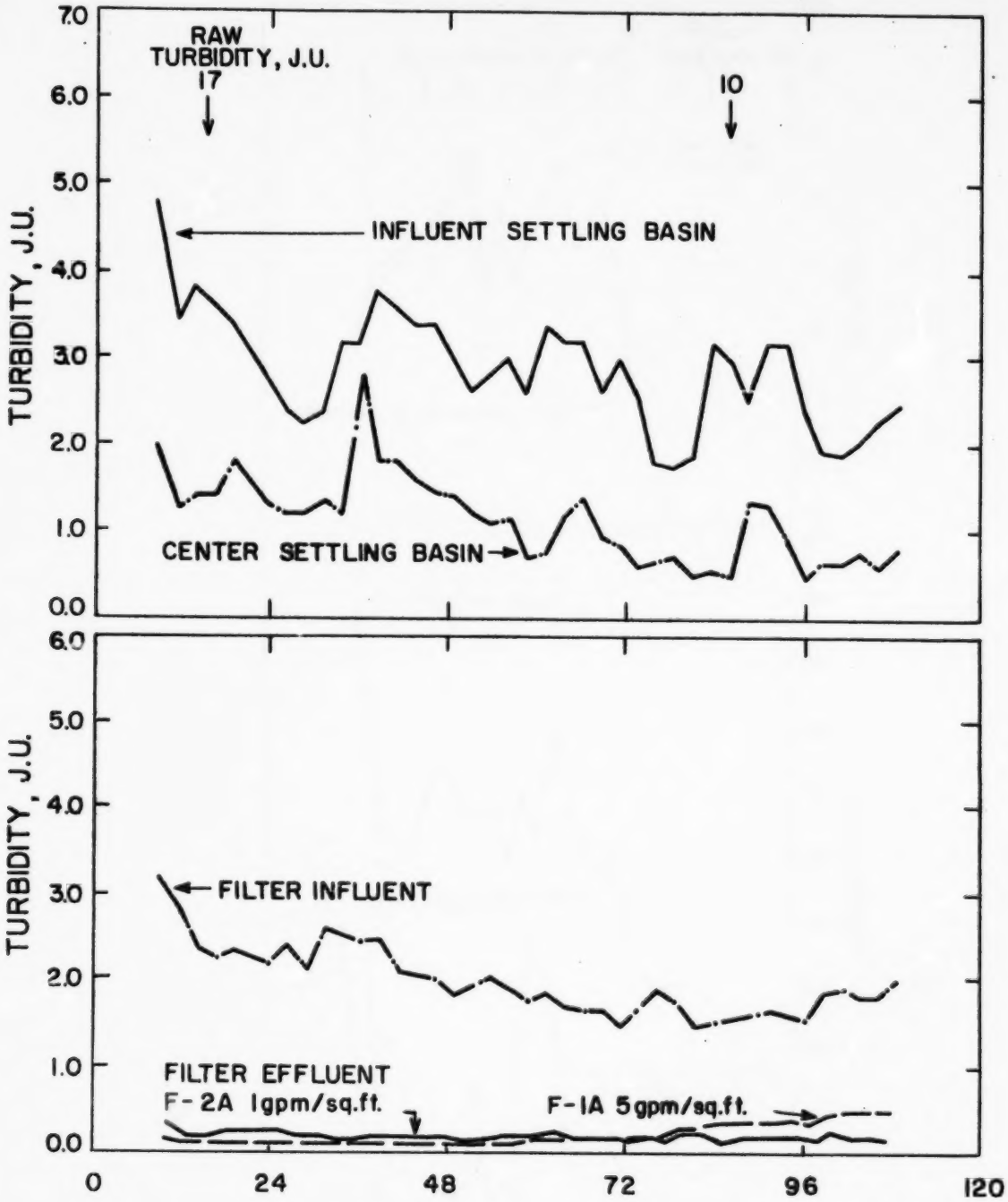
FIGURE 34



TURBIDITY VALUES FOR 1.4 AND 4.5gpm/sq.ft.
RATES USING ONLY 2 BASINS
RUN# 26, 1/30—2/2/61
FIGURE 35

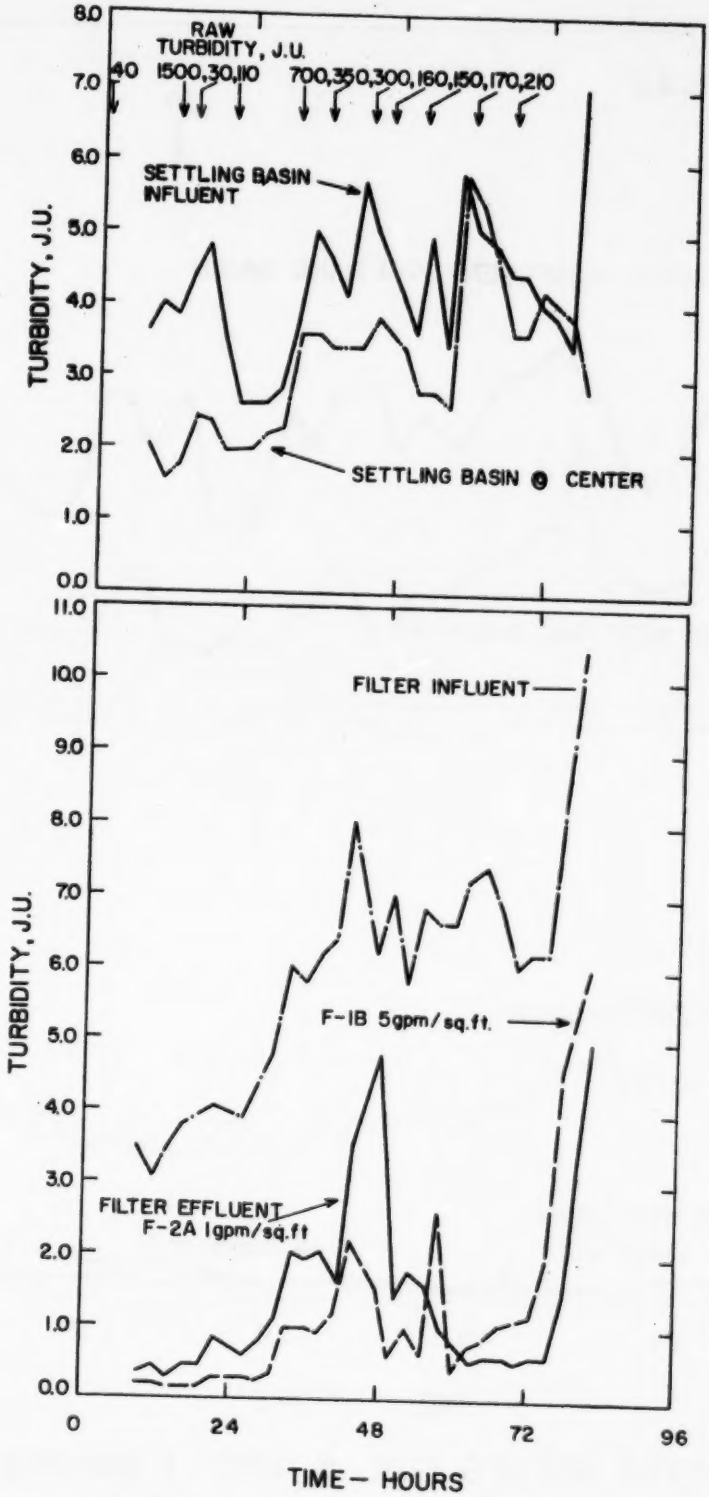


TURBIDITY VALUES FOR 4.5 AND 1.4 gpm /sq.ft.
RATES USING ONLY 2 BASINS
RUN # 27, 2/6 — 9/61
FIGURE 36



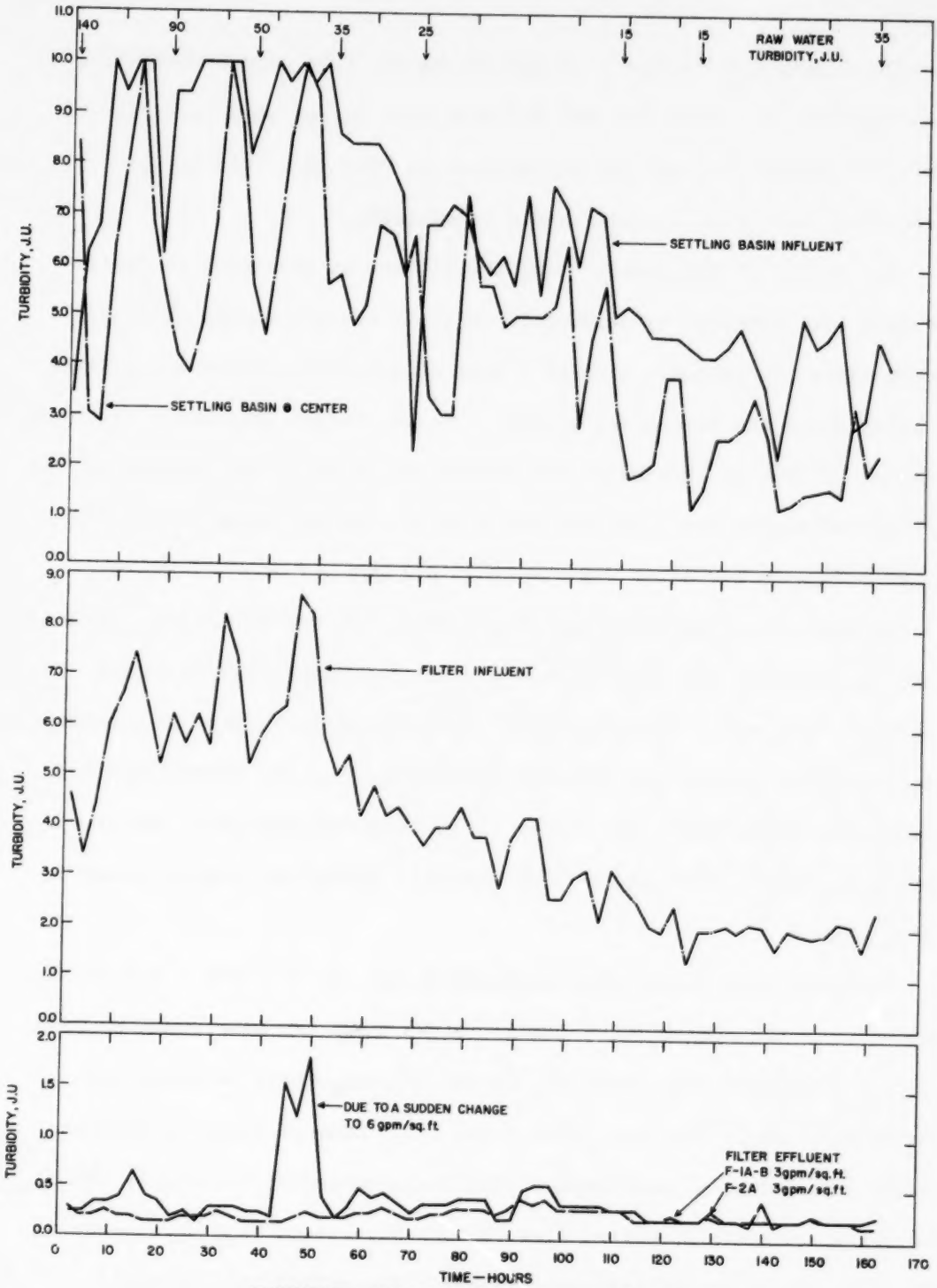
TURBIDITY VALUES FOR 5 AND 1 gpm/sq.ft.
RATES USING ONLY 2 BASINS
RUN # 28, 2/13 — 17/61

FIGURE 37



TURBIDITY VALUES FOR 5 AND 1 gpm/sq.ft.
RATES USING ONLY 2 BASINS
RUN# 29, 2/20 — 23/61

FIGURE 38



TURBIDITY VALUES FOR 3 gpm/sq. ft. RATE
USING 3 FILTERS AND 2 SETTLING BASINS
RUN# 30 4/17—26/61

FIGURE 39

run at the likely future rate of 3 gpm per square foot, would handle the floc carryover. All three filters did very well except when one rate was suddenly increased to 6 gpm per square foot at hour 42. This practice, regardless of the initial rate, should be avoided.

The amount of floc penetrating the filters is presented in Table 4. These data were obtained by passing 100 milliliters per minute of filter effluent water continuously through 1 gram of absorbent cotton for several days after which the cotton was burned. The ash weight presumably represented the amount of floc or turbidity that passed the filter. The results varied from 0.011 milligram per liter for run 4 at a 2 gpm per square foot rate to 0.308 milligram per liter for run 13 at a 1 gpm per square foot rate. Run 4 had adequate coagulation and strong floc, but run 13 did not. These conditions are borne out by the average gross turbidity reading during these runs: 0.1 and 0.8 respectively. Although gross changes in penetration through parallel filters are detected equally well by the cotton plug and turbidimetric measurement, the latter, when taken continuously, has the advantage of telling when and to what extent a gradual or sudden change has taken place.

Although some of the cotton plug data seem to indicate a greater floc penetration at the higher rates (runs 4 to 9) there are many examples in which the reverse is true (runs 13, 14 and 15) and others in which the penetration is about the same (runs 3 and 10). Some of these variations may have been due to a questionable sampling arrangement wherein it was difficult to maintain a desired flow through the cotton plug during the latter part of run on the high-rate filter. The method was therefore

Table 4. COMPARISON OF COTTON PLUG AND GROSS TURBIDITY DATA IN FILTER EFFLUENTS AT VARYING FLOW RATES

Season	Run no.	Filtration rate, gpm/sq ft		Cotton plug residue, mg/liter		Average turb., J.u.	
		F-1	F-2	F-1	F-2	F-1	F-2
Fall '59	3	2	5	0.106	0.094	0.30	0.30
"	4	2	5	0.011	0.120	0.10	0.20
"	5	3	4	0.021	0.030	0.20	0.30
"	6	3	4	0.134	0.183	0.25	0.30
"	7	4	3	0.045	0.031	0.15	0.15
"	8	4	3	0.130	0.045	0.20	0.20
"	9	4.8	2	0.122	0.036	0.20	0.20
"	10	4.8	2	0.015	0.016	0.15	0.15
"	11	5.7	1	0.265	0.024	0.20	0.15
"	12	5.7	1	0.103	0.024	0.20	0.15
Spring '60	13	5.5	1	0.093	0.308	0.70	0.80
"	14	5	1	0.133	0.141	0.30	0.30
"	15	4.2	2.2	0.017	0.050	0.10	0.10
"	16	4.2	2.2	0.056	0.020	0.30	0.04
"	17	3.3	3.3	0.079	0.175	0.30	0.30

discontinued after run 17.

To determine how many particles of various sizes were passing through the filters at different rates, samples of filter influent and effluent were collected and shipped to SEC to be put through a particle counter and sizer.

As might be expected there was difficulty in maintaining both the floc particle size and the number during transit despite the use of preservatives and of shaking before testing. Hence, there were variations in the data that could not be accounted for. Table 5 (in three parts) illustrates that the number of particles for a 1.15 to 1.44 micron range in runs 6, 9, and 10 varied from 7,730 (in run 10) to 224,520 per 0.25 milliliter (in run 6), even though the original turbidities were similar. The total volume of particles passing the filter should have given some relative indication of removal in parallel filters, as the cotton plug had done, but the results on run 6 were confusing on this basis, too, since a greater volume of particles came out than went into the filter. Although runs 9 and 10 produced better results, the aging of samples during shipment was too much of a variable, so the particle-counting technique was discontinued after run 10.

Coliform Penetration

The coliform loadings and passage through the plant units are presented in Table 6, and generally indicate that the coagulation basin usually removed over 99 percent of these organisms. This made an evaluation of coliform passage through filters operated at various rates rather difficult. There is no indication that coliform penetration was greater at high filter rates of 4 to 6 than at 1 to 2 gpm per square foot rates.

Table 5-1. SIZE AND NUMBER OF PARTICLES IN RAW, COAGULATED, AND FILTERED WATER, RUN NO. 9. SAMPLES COLLECTED 6:30 a.m., NOV. 2, 1959, COUNTED 4 p.m., NOV. 4, 1959

COUNTS PER 0.25 ml of UNDILUTED SAMPLE

Size, microns	Raw Water	Filter influent to #1 & #2	Filter #1 effluent	Percent passing F-1	Filter #2 effluent	Percent passing F-2
> 7	1,200	90	110	100	50	56
6-7	450	80	30	38	10	13
5-6	800	180	130	72	70	39
4-5	4,350	390	560	100	270	69
3-4	6,800	1,690	1,140	67	470	28
2-3	21,150	5,640	4,090	73	2,870	51
1.44-2	91,800	27,060	24,620	91	14,360	53
1.15-1.44	240,400	145,820	69,530	48	34,460	24
Hach turb, J.u.	< 25	1.3	0.3		0.2	
Volume of particles		378,000	274,000	72	144,000	38
Cotton plug for entire run, mg/liter			0.122		0.036	
Flow rate, gpm/sq ft			4.8		2	

Table 5-2. SIZE AND NUMBER OF PARTICLES IN RAW, COAGULATED, AND FILTERED WATER, RUN NO. 10. SAMPLES COLLECTED 6:30 a.m., NOV. 9, 1959, COUNTED 1 p.m., NOV. 10, 1959

COUNTS PER 0.25 ml OF UNDILUTED SAMPLE

Size, microns	Raw Water	Filter influent to #1 & #2	Filter #1 effluent	Percent passing F-1	Filter #2 effluent	Percent passing F-2
> 7	500	20	20	100	20	100
6-7	250	20	20	100	0	0
5-6	300	100	20	20	60	60
4-5	1,400	190	150	79	60	32
3-4	3,700	540	250	46	190	35
2-3	12,500	2,560	650	25	440	17
1.44-2	54,650	10,410	2,100	20	1,990	19
1.15-1.44	268,600	21,870	7,730	35	13,250	60
Hach turb, J.u.	< 25	0.6	0.2		0.2	
Volume of particles		110,172	42,250	38	41,000	38
Cotton plug, mg/liter			0.015		0.016	
Flow rate, gpm/sq ft			4.8		2	

Table 5-3. SIZE AND NUMBER OF PARTICLES IN RAW, COAGULATED, AND FILTERED WATER, RUN NO. 6. SAMPLES COLLECTED 6 to 7 a.m., SEPT. 28, 1959, COUNTED 2 p.m., SEPT. 29, 1959.

COUNTS PER 0.25 ml OF UNDILUTED SAMPLE

Size, microns	Raw Water	Filter influent to #1 & #2	Filter #1 effluent	Percent passing F-1	Filter #2 effluent	Percent passing F-2
> 7	200	63	26	41	48	76
6-7	220	71	24	34	38	54
5-6	285	148	56	38	64	43
4-5	640	239	121	51	272	100
3-4	1,890	884	707	80	1,138	100
2-3	12,165	5,074	4,897	97	6,908	100
1.44-2	81,205	22,849	27,112	100	29,200	100
1.15-1.44	724,195	191,308	215,951	100	224,520	100
Hach turb, J.u.	< 25	0.6	0.1		0.1	
Volume of particles		398,000	400,000	100	458,000	100
Cotton plug, mg/liter			0.134		0.183	
Flow rate, gpm/sq ft			3		4	

Table 6. COLIFORM LOADING AND PASSAGE, PER 100 ml

Date	Plant influent	Filter influent	Filter 1 effluent		Filter 2 effluent	
			Flow rate, gpm/sq ft	Coliforms	Flow rate, gpm/sq ft	Coliforms
8/25/59	6,900	?	1	37	6	32
8/27	4,800	112	1	20	6	15
8/31		320	1	< 1	6	1
9/4	4,000	6	2	< 1	5	1
9/6	3,000	8	2	1	5	< 1
9/9	2,000	8	2	< 1	5	3
9/11	500	17	2	6	5	5
9/14	4,200	5	2	< 1	5	2
9/16	7,000	20	2	1	5	2
9/20	1,800	13	3	5	4	< 0.5
9/22	9,000	28	3	1	4	2
9/28	800	8	3	2	4	< 1
9/29	7,100	20	3	5	4	8
9/30	4,100	35	3	7	4	11
10/6	2,500	5	4	3	3	< 0.5
10/10	4,200	11	4	5	3	< 1
10/11	4,700	54	4	5	3	8
10/14	2,800	20	4	28	3	20
10/15	8,400	9	4	0.5	3	2
10/28	500	2	5	< 0.5	2	< 0.5
10/29	1,000	1	5	2	2	1
11/1	1,000	10	5	1	2	< 0.5

Table 6. Continued

Date	Plant influent	Filter influent	Filter 1 effluent		Filter 2 effluent	
			Flow rate, gpm/sq ft	Coliforms	Flow rate, gpm/sq ft	Coliforms
11/4	2,600	16	5	< 0.5	2	0.5
11/6	1,700	1	5	< 0.5	2	< 0.5
11/10	460	1	5	< 0.5	2	< 0.5
11/12	350	1	5.7	< 0.5	1	< 0.5
11/13	450	1	5.7	< 0.5	1	< 0.5
11/14	320	< 0.5	5.7	< 0.5	1	< 0.5
11/17	400	2	5.7	< 0.5	1	< 0.5
11/18	310	< 0.5	5.7	< 0.5	1	< 0.5
11/19	1,600	2	5.7	5	1	< 0.5
3/30/60	6,600	14	5.5	13	1	4
4/5/60	520	< 2	5	< 1	1	< 1
4/6	660	1	5	< 1	1	< 1
4/7	300	< 1	5	< 1		< 1
4/12	320	1.5	4.2	< 0.5	2.2	< 0.5
4/14	890	1	4.2	0.5	2.2	0.5
4/17	160	1.5	4.2	< 0.5	2.2	< 0.1
4/19	270	2.5	4.2	0.5	2.2	< 0.5
4/20	260	0.5	4.2	< 0.5	2.2	0.5
4/22	missed(?)	31	4.2	1	2.2	8
4/26	2,800	15	3.3	< 1	3.3	22
4/27	1,200	25	3.3	5	3.3	12
4/28	1,200	20	3.3	5	3.3	9

Table 6. Continued

Date	Plant influent	Filter influent	Filter 1 effluent		Filter 2 effluent	
			Flow rate, gpm/sq ft	Coliforms	Flow rate, gpm/sq ft	Coliforms
11/8/60	450	< 1	2.2	< 1	4.0	< 1
11/9	250	< 1	2.2	< 0.5	4.0	< 0.5
11/10	500	2	2.2	< 0.5	4.0	< 0.5
11/15	160	< 0.5	2	< 0.5	4	< 0.5
11/16	180	0.5	2	< 0.5	4	< 0.5
11/17	330	0.5	2	< 0.5	4	0.5
11/28	160	< 0.5	1.4	< 0.5	4.5	< 0.5
11/29	200	1	1.4	< 0.5	4.5	< 0.5
11/30	230	< 0.5	1.4	1.5	4.5	< 0.5
12/5/60	80	< 0.5	1.4	< 0.5	4.5	< 0.5
12/6	80	< 0.5	1.4	< 0.5	4.5	< 0.5
12/7	130	4.5	1.4	< 0.5	4.5	< 0.5
12/13	95	< 0.5	1	< 0.5	5	< 0.5
12/14	150	< 0.5	1	< 0.5	5	< 0.5
12/15	235	< 0.5	1	< 0.5	5	< 0.5
1/3/61	150	< 0.5	1	< 0.5	5	< 0.5
1/4	200	< 0.5	1	< 0.5	5	0.5
1/9	100	< 0.5	4	< 0.5	2	< 0.5
1/11	22	< 0.5	4	< 0.5	2	< 0.5
1/12	52	< 0.5	4	< 0.5	2	< 0.5
1/16	100	< 0.5	4	< 0.5	2	< 0.5
1/17	30	< 0.5	4	< 0.5	2	< 0.5
1/19	110	1	4	< 0.5	2	< 0.5

Table 6. Continued

Date	Plant influent	Filter influent	Filter 1 effluent		Filter 2 effluent	
			Flow rate, gpm/sq ft	Coliforms	Flow rate, gpm/sq ft	Coliforms
1/30	34	< 0.5	4.5	< 0.5	1.4	< 0.5
1/31	48	< 0.5	4.5	< 0.5	1.4	< 0.5
2/1	41	< 0.5	4.5	< 0.5	1.4	< 0.5
2/6	130	< 0.5	4.5	< 0.5	1.4	< 0.5
2/7	250	9	4.5	6	1.4	< 0.5
2/8	240	6	4.5	0	1.4	4
2/13	68	< 0.5	5	< 0.5	1	< 0.5
2/15	26	1	5	< 0.5	1	< 0.5
2/16	15	< 0.5	5	< 0.5	1	< 0.5
2/20	290	1	5	< 0.5	1	1
2/21	710	5	5	5	1	1
2/22	230	1	5	1	1	1
4/16	2,200	< 0.5	3	< 0.5	3	< 0.5
4/19	1,500	1	3	< 0.5	3	< 0.5
4/20	580	0	3	< 0.5	3	0.5

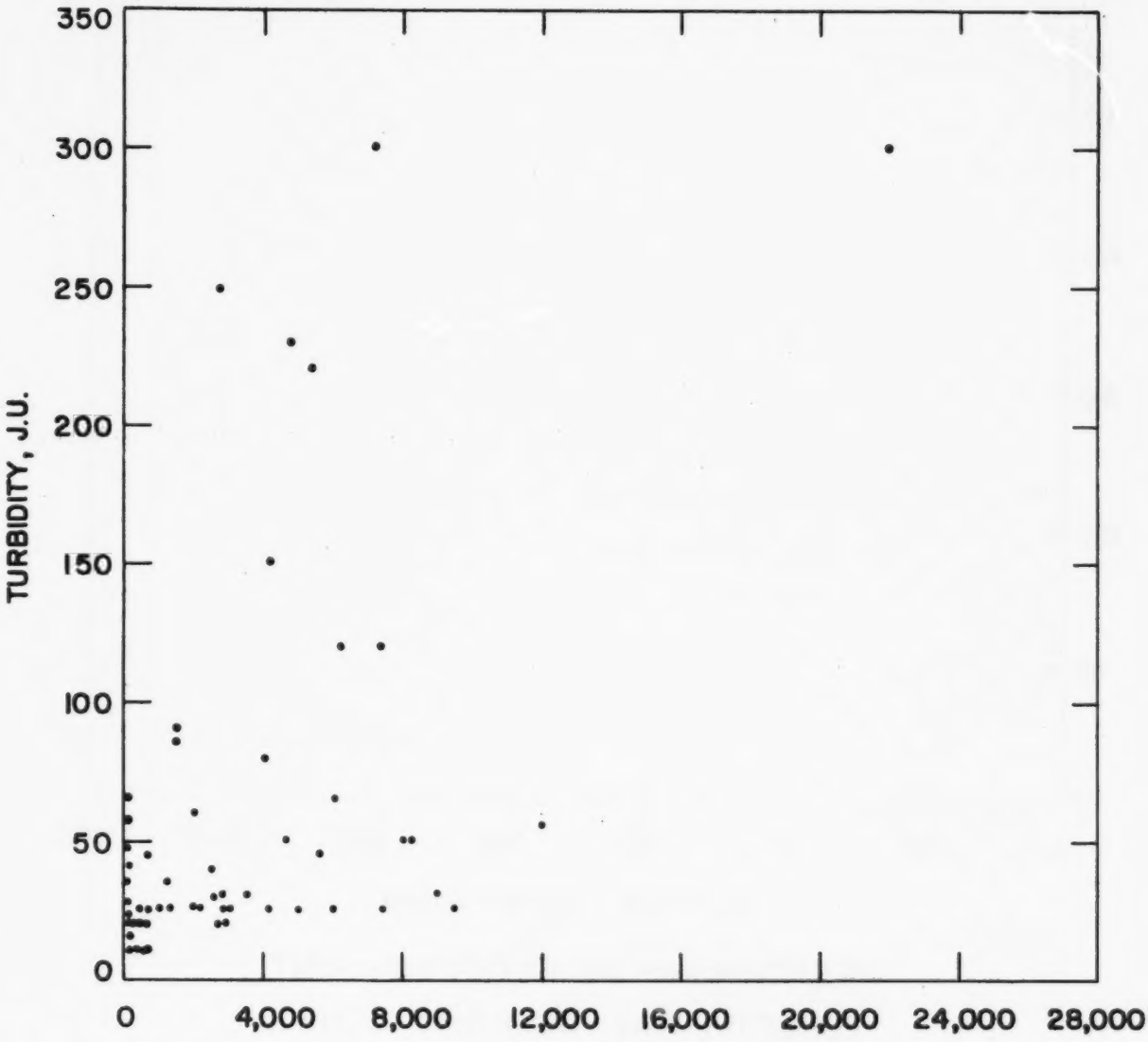
Even though some filter effluents showed passage of coliforms, none of the 200 milliliter portions of finished tap water showed any coliforms. This tap water was chlorinated just after filtration and before entering the clear well.

The lack of correlation between raw water turbidity and coliform is illustrated by the scattered points in Figure 40. Generally there was a definite increase in the number of coliforms in the raw water when the turbidity increased greatly. There were, however, many occasions when the coliform count went up in the summer without a corresponding increase in turbidity. This may have resulted in part from the dual source of raw water and their differences in coliform content. These two waters were frequently mixed in varying percentages or used exclusively for short periods, and consequently, grab samples at the chemical feed house could not be traced back precisely to their origin.

As seen in Figures 41 and 42, there is also a poor correlation between turbidity and coliform counts in both filter influent and effluent. Unfortunately, not many basin or filter samples were taken during times of basin upset or filter breakthrough, so the picture on this relationship is not complete.

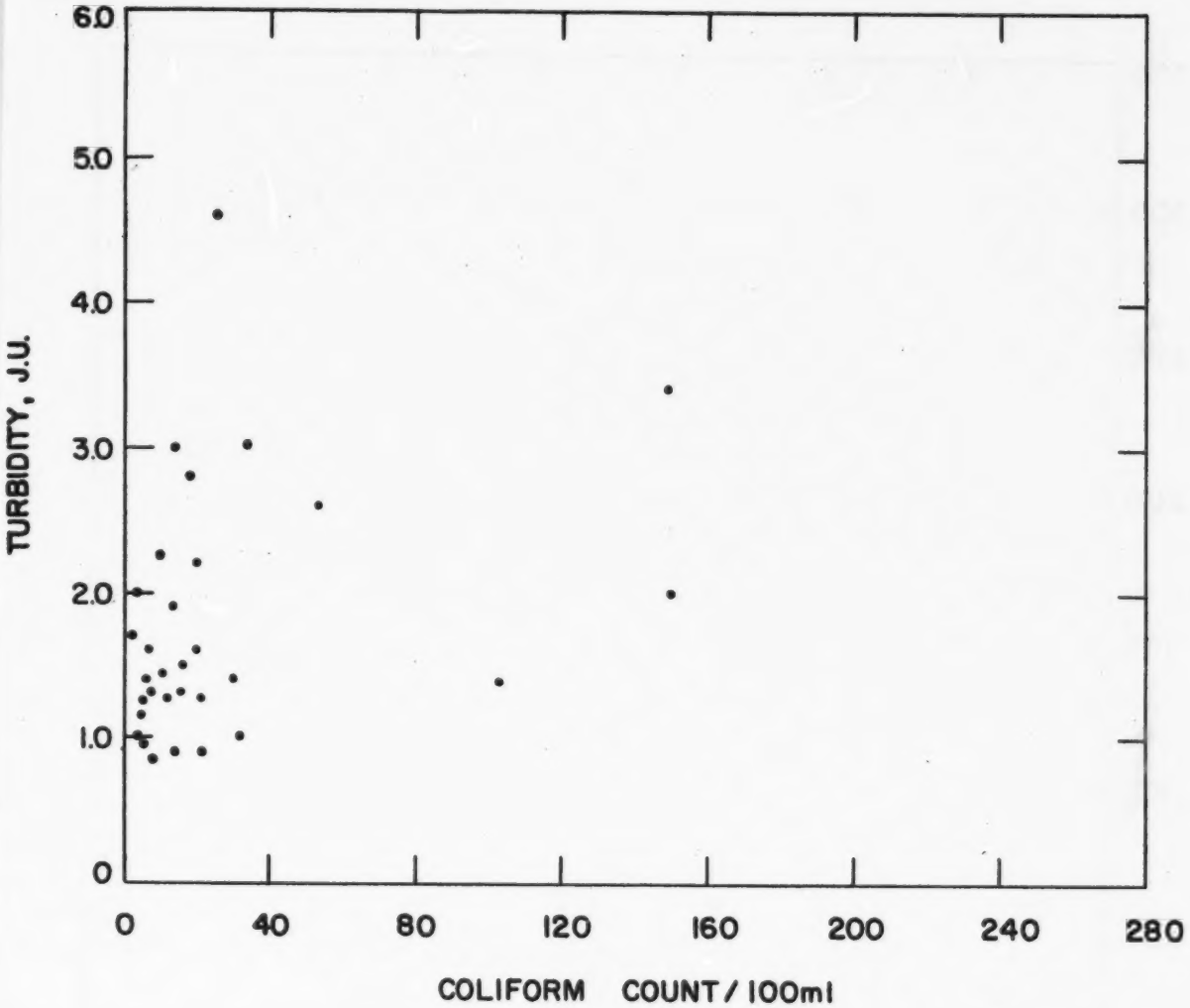
Length of Runs

The filter runs were long, ranging from 60 to over 163 hours for the high flow rates (Table 2). A few runs probably should have been stopped sooner when the effluent turbidity suddenly increased over 1.0 or even when it exceeded 0.5 Jackson units.



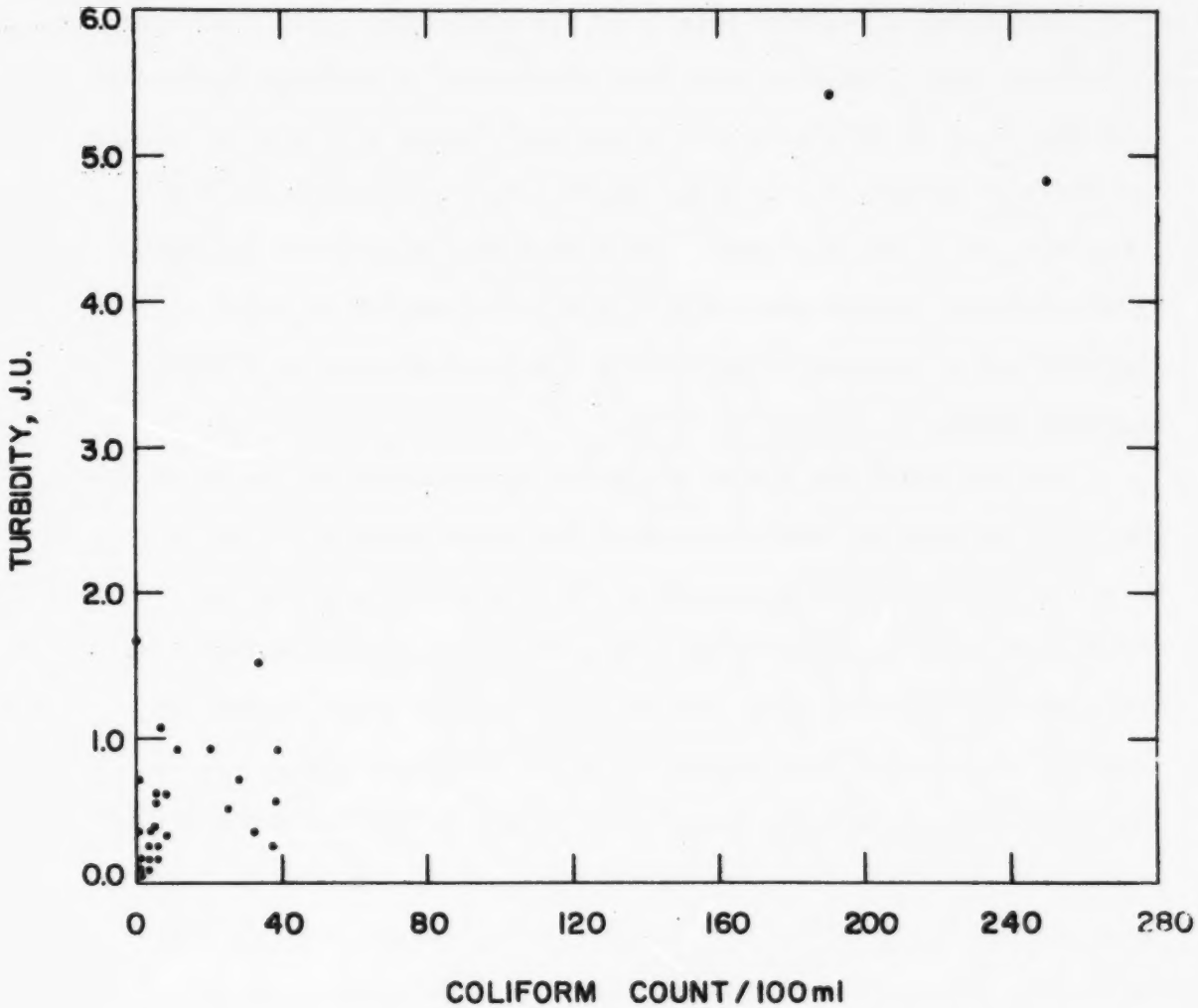
RELATIONSHIP OF RAW WATER TURBIDITY AND COLIFORM COUNT.

FIGURE 40



RELATIONSHIP OF FILTER INFLUENT
TURBIDITY AND COLIFORM COUNT

FIGURE 41



RELATIONSHIP OF FILTER EFFLUENT
TURBIDITY AND COLIFORM COUNT

FIGURE 42

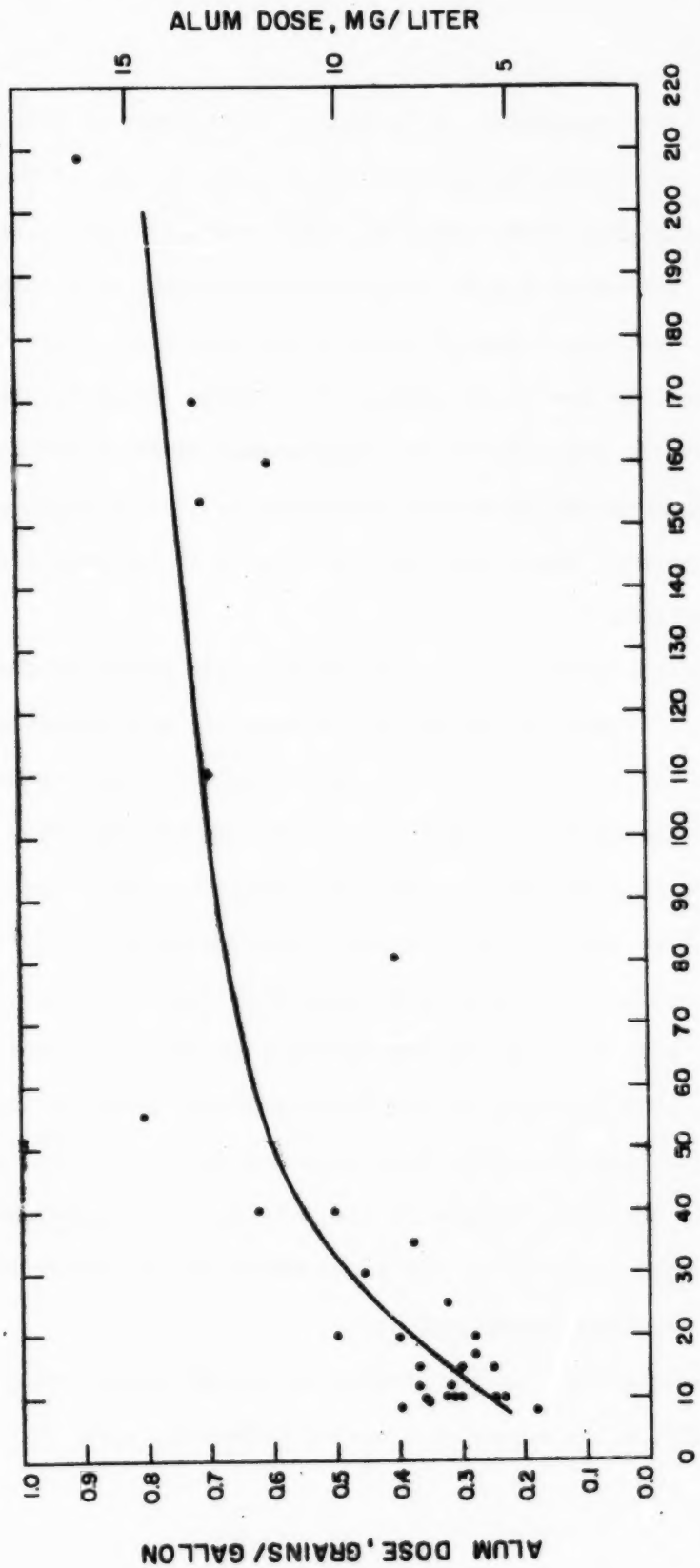
The amount of backwash water used per month under these conditions is so minor that it probably would be a good policy to backwash the filters on a time basis of 60 to 72 hours, unless the effluent turbidity or headloss is sufficient to warrant a stoppage sooner. This is particularly true at 1 to 3 gpm per square foot rates. The good condition of these anthracite filters (without surface wash) after 7 years of operation to only 2 or 3 feet headloss is substantiating evidence that this practice is justified.

Coagulant Demand

The low alkalinity and pH of the raw water limited the amount of alum that could be used for coagulation since the pH was depressed to below 5 by overdosing. The operator usually tried, however, to overcome the adverse effect of turbidity by increasing the alum dose from perhaps 5 to 10 milligrams per liter but never over 20 milligrams per liter. Figure 43 shows the variation in dose tried with various turbidity loadings in the winter of 1961. No complete picture is available of the circumstances that caused high turbidity to persist through the plant in runs such as those shown in Figures 10, 11, 12, 15, and 38. It is, however, possible that higher alum doses with some chemical additions for alkalinity and pH control, and floc strengthening might have prevented these periods of poorly clarified water.

DISCUSSION

Monitoring turbidity and temperature continuously at several places in the Gaffney plant demonstrated that trouble can be anticipated well ahead of filtration. An increase in basin water turbidity was an indication that flocculation and coagulation were not adequate and that turbid water was likely



COAGULANT USED WITH VARIOUS TURBIDITY LOADINGS.

FIGURE 43

to come from the filter regardless of flow rate. Using part of the large settling basin for mechanical flocculation might overcome some of these problems. More meaningful corrective steps could probably come, however, from a short-time, laboratory-scale, coagulation-filtration pilot plant. This could help to indicate, ahead of actual plant throughput, what alum, lime, or polyelectrolyte dose would produce floc strong enough to stay in the filter. Efforts of this kind at the experimental plant at the Robert A. Taft Sanitary Engineering Center (2) and by Conley (3)(4) indicate that this technique is more helpful than a jar test alone since it involves filtering as well as some settling.

If any polyelectrolyte, such as activated silica or one of the synthetic materials, is used in the filter influent, it will probably be necessary to use a surface wash to remove the sticky floc from the media.

The lack of correlation between the filter effluent turbidity and coliform counts during high turbidity periods, results in part from the limited number of grab samples for coliforms taken during poor water periods. The low coliform loading made analysis of flow rates very difficult. Nonetheless, other data collected at the Sanitary Engineering Center (2) indicate that increased turbidity in the filter effluent means an increase in organism passage, providing there were organisms applied to the filter; every effort should therefore be made to use both the settling basins and filters to the utmost at all times. This may reduce the necessity for higher chlorine doses during troublesome periods.

Seasonal factors were not too pronounced, though better water was usually produced during the winter when sudden increases in raw water turbidity

were at a minimum. High summer temperatures caused the open settling basin to be upset for a few hours each day, which decreased the safety factor built into the basin so that any additional coagulation problems caused a quick increase in the filter effluent turbidity. Perhaps covering the basins to overcome this problem would be too expensive, but installation of multiple outlets across the basins during original construction may reduce the effects of temperature in future plants.

CONCLUSIONS

1. Increasing the flow rate from 2 to 6 gpm per square foot through the anthracite filter beds at Gaffney, S. C., water plant did not significantly increase the passage of turbidity or coliforms during selected test periods starting in 1959 and ending in 1961. The results were similar when the settling basins were overloaded ahead of the high-rate filter.
2. Increases in filter effluent turbidity did occasionally occur, but the penetration at 1 gpm per square foot rate was as great as it was at 6 gpm per square foot. These unexpected results were attributed to inadequate coagulation ahead of the filter for limited but significant periods.
3. Sudden increases in raw water turbidity seemed to cause the coagulation difficulties.
4. The open settling basins were somewhat upset daily by the sun during part of the year.
5. Even though prechlorination was discontinued during the test periods, the > 99 percent reduction of coliform in the large

settling basins made it difficult to evaluate the efficiency of filters to remove these organisms at various rates.

6. Monitoring raw, settled, and filtered water continuously or at frequent intervals is a good way to anticipate coagulation troubles and to check the relative success of modification in chemical doses or flow rates.

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4. Conley, W. R., "Experience with Anthracite-Sand Filters." Jour. Am. Wat. Wks. Assn., 53:1473 (December 1961).

APPENDIX A

General Instructions for Monitoring the Plant Performance*

I. Turbidity

A. Turbidimeter

1. General

The Hach turbidimeter measures light scattered 90° from suspended solids in the water. The submerged photocells in the instrument that pick up the scattered light are sealed by glass windows, which must be kept clean. It is necessary to calibrate this instrument in terms of standard turbidity units by using a dilution technique. This is done by obtaining a sample turbid enough to be read accurately on the Jackson Candle Turbidimeter (greater than 30) and then, by diluting with varying amounts of particle-free water, obtain turbidity values for Hach readings that will allow plotting of a calibration curve. (It is virtually impossible to get particle-free water; this goal can, however, be approached by using carefully cleaned glassware and filtering a well-coagulated water slowly through a small, fine sand filter. Some have used a fine membrane filter or double-distilled water for this purpose, but with only limited success,)

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*Two visits during the first summer, each about 10 days, were made by two people from SEC to help install the monitoring equipment and train the operators. Consequently, the instructions left with the operators were only general.

If the turbidimeter is to be used for flocculated or filtered water, then use alum floc to make up the original suspension that is to read at least 30 J.u. Likewise, native suspended solids should be used when dealing with raw water readings.

2. Installation

This unit should preferably be installed in a filter pipe gallery, so it can be fed by gravity or siphons, since pumping usually causes a release of air or breaks up particles and may produce invalid results. Use a 3-way valve or multioutlet header to divert the desired stream from the settling basin or filters through the detector for 20 or 30 minutes.

3. Standardization

a. Galvanometer

(1) Disconnect one lead and check zero reading.

(2) Reset zero with knob inside box if necessary.

b. Turbidimeter

(1) Stop flow to turbidimeter.

(2) Connect shunt on galvanometer and take reading.

(3) Insert stainless steel rod into chamber instrument and take reading.

(4) Subtract (2) from (3). Answer should be around 10 to 12.

(5) If reading is too high, remove lamp assembly from top, wipe off the glass surfaces over the photocells, and recheck standard.

c. Operation

(1) Only one sample line should be open at a time.

(2) Galvanometer readings should be taken about every 1/2 hour and just before a valve change is made. This will assure a valid reading not influenced by the previous sample.

B. Cotton Plugs

1. A small plastic funnel, 1 inch in diameter, and with a tapered bottom and a rubber stopper on top, has been arranged to hold 1 gram of absorbent cotton, through which some water from the filters will flow. The flow of 100 milliliters per minute is controlled downstream by a float valve in an open 1-gallon tank. This tank has a small stainless nipple screwed into the bottom to serve as a drain. A cap with a small hole is screwed onto the nipple to act as the controlling orifice. The flow rate through this orifice must be measured each shift with a 100-milliliter graduate and stop watch, and, if it is less than 95 milliliters per minute, check for the following possible causes:

a. Orifice may be clogged, if so, clean it;

b. cotton plug may be too clogged, if so, reset float to increase head on orifice;

c. headloss through the regular anthrafilt filter may be too great (When this filter headloss exceeds 3 1/2 feet, which it will do during the latter part of the run for the high-

rate units, there may not be enough pressure to force 100 milliliters through the partially plugged cotton. In this case, the flow through the cotton plug should be measured and recorded about every 2 hours so the total flow through the plug can be correctly calculated.)

2. Rate of flow through the cotton plug may be controlled by:
   a. Decreasing or increasing the head on the orifice by resetting the float,
   b. using orifice of smaller or larger size.
3. Use 1 gram of cotton as provided and change cotton whenever there seems to be an excess of foreign material in the plug sufficient to cause noticeable passage through it.
4. Ship used cotton plug to SEC in a clean, polyethylene bottle, as provided, with all details of filter run such as number of hours, rate, date, time on, time off. The cotton sample will be ashed, and the net weight can then be converted to milligrams per liter since the total amount of water put through is known.

C. Particle Count Samples

Collect a 100 milliliter sample of the filter influent and effluent in a clean bottle and ship to SEC where a particle counter will be used to determine how many particles of various size ranges have passed through the filters.

II. Microbiological

A. For the weeks beginning August 23 and August 30, send samples for delayed coliforms to SEC.

B. Run standard membrane filter coliform test daily on:

1. Plant influent; use three portions, 0.1, 1, and 10 milliliters;
2. filter influent and the two filter effluent; use two portions, the size depending on success of coagulation and filtration;
3. tap water; use 200 milliliter portions.

C. Run coliform test weekly for the Broad River and Cherokee Creek.

D. Take additional samples for coliforms at such times as indicated by a rise of turbidity or adverse conditions in the filter.

E. Run 200 milliliters of filtered water through membrane filter and observe for algae and debris daily.

III. Temperature Measurements

By using the telethermometer and 100-foot leads, measure the water temperature:

A. At entry to the settling basin;

B. at 6-inch, 3-foot, and 9-foot depths at the middle of the settling basin;

C. at 1-foot and 9-foot depths near the end of the basin;

D. at the filter gullet.

Do this at least two times per shift. A recommended schedule would be 3 a.m., 6 a.m., 12 noon, 4 p.m., 7 p.m., and 11 p.m. The above is only a minimum recommendation. It may be advantageous to take

measurements at more points and depths in the settling basin until a typical pattern for a particular season or time of the day is established.

IV. Headloss Readings

Headloss readings on the temporarily installed water piezometers can be taken only when the filter effluent sample line to the turbidimeter is off. These readings should be taken every hour and a half. The run shall stop when one of the two filters reaches a headloss of 6 feet. Send a copy of data to SEC.